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**DROP ORIENTATION ANALYSES
OF THE CONCRETE INTEGRATED CONTAINER**

Report No. 90-221-K

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ABSTRACT

The Nuclear Engineering Department is currently investigating the use of a reinforced concrete integrated container (CIC) for dry storage, transportation, and possible final disposal of irradiated fuel. The system is composed of the container and the impact limiters to protect both the top and bottom ends of the CIC. This system is under investigation for the structural integrity of the container assuming a nine meter top-down corner drop onto a rigid target.

Three finite element impact analyses based on drop orientations of: 1) C.G. directly above the initial impact point, 2) 5° vertically tilted drop, and 3) 5° horizontally tilted drop have been carried out to decide the most critical drop orientation in support of the Phase II drop tests, as well as for investigating structural response in the final design of the CIC and the impact limiter.

It is concluded that, although there is no damage to the container, the drop orientations of Cases 1 and 2, in that order of priority, are recommended for the experimental tests. On the other hand, Case 3 could be of interest to study the damage of the impact limiter itself.

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EXECUTIVE SUMMARY

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Ontario Hydro is presently investigating the use of a reinforced concrete container (CIC) for dry storage, transportation and possible final disposal of irradiated fuel. In order to study the structural integrity to meet licensing requirements, experiments to simulate an accidental drop of the CIC during operation are to be carried out. Even though a scenario of nine meter top-down corner drop onto a rigid target is to be considered, the drop orientation which varies from 0 to 180 degrees remains to be decided. In support of the decision for these tests, stress analyses to simulate such an impact at different orientations have therefore been conducted. The objective is to determine the drop orientation which causes the maximum damage on the CIC.

This report describes in detail the analyses being performed. The structural system is composed of the container itself and the impact limiters to protect both the top and bottom ends of the CIC. Three finite element impact analyses based on drop orientations of: 1) C.G. (center of gravity) directly above the initial impact point, 2) 5° vertically tilted drop, and 3) 5° horizontally tilted drop, are carried out. The impact response and damage of the system in terms of energy, momentum, contact force, stress, strain and deformation are closely examined and compared.

It is found that the container did not experience any significant damage in all three cases since the damage has been absorbed by the impact limiter. However, the stress and strain generated in the CIC in Cases 1 and 2 are higher than that in Case 3 and hence these two orientations are recommended for the drop tests. Furthermore, Case 1 is judged more vulnerable to a shear failure at the lid/container closure than Case 2 and hence should be considered with higher priority. On the other hand, the orientation of Case 3 could be of interest for studying the impact limiter itself.



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**DROP ORIENTATION ANALYSES
OF THE CONCRETE INTEGRATED CONTAINER**

1.0 INTRODUCTION

In the CIC (Concrete Integrated Container) program, a series of drop tests have been performed in Phase I (the dry storage phase) and more tests are to be carried out in Phase II (the transportation phase). All the containers tested in Phase I, either with or without impact limiters, were dropped in an orientation that the C.G. (center of gravity) was directly above the initial contact point and was based on the assumption that such a drop orientation would cause the most critical damage to the CIC. Even though this orientation was chosen on the basis of engineering judgment, it is felt that a detailed analysis was necessary and would be required prior to subsequent licensing tests. For this reason, a series of impact stress analyses considering various drop orientations were conducted. The objectives are:

Primary: To decide the drop orientation which causes the most critical damage to the container.

Secondary: To investigate the response and damage of the impact limiters.

For completeness this analytical investigation attempts to cover the entire spectrum of the possible orientations (i.e. 0° - 180°). This consideration results in the following three orientations (see Fig. 1) being chosen for analysis.

- Case 1: C.G. directly above the initial impact point
- Case 2: 5° tilted vertical drop
- Case 3: 5° tilted horizontal corner edge drop

All three cases are nine metre top-down free corner drops impacting onto a rigid ground. Case 1 is the same drop orientation being used in the Phase I tests and the necessity of including this orientation is obvious. Cases 2 and 3 provide coverage for the two extremes of near 0° and 180° , respectively. The 5° tilted position allows prediction for the imperfect vertical and horizontal drops (i.e. 0° and 180°) while, at the same time, correlates the drop toward 90° (i.e. Case 1). It was therefore felt that additional intermediate orientations such as at 45° and 135° can be eliminated.

2.0 GEOMETRY OF THE CIC SYSTEM

The complete CIC structural system is composed of the container and two impact limiters. These are described in the following:

2.1 Container

Fig. 2 provides a section and a plan view of the container. It is a thick rectangular concrete tank with a lid at the top. The tank has a height of 3.002m with the thickness of the lid being 0.480m. Adding these two numbers together, the complete container possess a total height of 3.482m. The tank has an outside dimension of 2.110m x 2.418m and an inside dimension of 1.012m and 1.320m.

Both outside and inside of the container, as well as the lid itself, are enclosed by 12mm steel plate. Within the enclosed plates, both the tank and the lid are filled with high density concrete. The lid is finally seal-welded to the tank along their corresponding perimeters.

The information regarding concrete reinforcement was not available at the time of analysis. Since the current investigation is a relative comparison between the three orientations, the contribution by the reinforcement, which is judged to be less significant, is ignored.

2.2 Impact Limiter No. 1

Impact limiter No. 1 is defined as the limiter covering the lid end of the CIC (see Fig. 3). It is basically a rectangular hollow structure sheathed by 304L stainless steel (S.S.) and filled with rigid polyurethane foam.

The portion to directly protect the lid is enclosed by 10mm thick horizontal S.S. (stainless steel) plates and vertically by 5mm thick S.S. plates all around with 1.005m in height. There is a 1.0m x 1.0m x 0.5m cubic cavity in the center. This portion of the limiter is filled with 15 lbs/ft³ density rigid foam.

The projected portion is designed to protect the sides of the CIC. The outer skin is composed of 5mm thick S.S. plates while the inner skin by 5mm S.S. plates on two opposite sides and 10 mm S.S. plates on the other two opposite sides. The projected height is 1.215m which leads the total height of the impact limiter No. 1 to 2.220m. This portion is filled with 17 lbs/ft³ density foam.

2.3 Impact Limiter No. 2

Impact limiter No. 2 is defined as the limiter covering the other end (bottom end) of the CIC (see Fig. 4). This limiter is identical to Impact limiter No. 1 except that the projected height to protect the sides of the CIC is reduced to 0.615m. The total height of the limiter is therefore 1.620m and is 0.6m shorter than that of the impact limiter No. 1.

3.0 MATERIAL PROPERTIES

There are four different types of material involved: 1) the structural mild steel for the CIC liners, 2) the CIC filled high density concrete, 3) the stainless steel for the impact limiter skin, and 4) the rigid polyurethane foam which fills the impact limiter. The rigid foams are further divided into two types of 17 lbs/ft³ and 15 lbs/ft³ density respectively. Their mechanical properties are reported in the following:

3.1 Steel Liners

The steel liners are made of CSA G40.21 300 WT which has a guaranteed minimum yield strength of 300 MPa. However, the actual yield strength can be significantly higher. Fig. 5, as supplied by the Nuclear Engineering Department, shows a stress-strain curve tested by STELCO indicating a yield strength of approximately 370 MPa. A recent experiment conducted by ORTECH indicated that the yield strength was as high as 500 MPa (Ref. 1). The yield strength in the analysis is therefore increased from 300 MPa to 370

MPa based on the Fig. 5 to avoid being over conservative while still leaving ample margin of safety when compared with that of Ref. 1.

Linear strain hardening (see Fig. 5) is assumed in order to fit to the input format of the computer program. Judging that the container may not experience significant plastic strain as it is being protected by the impact limiter, it is decided that the linear approximation should resemble the earlier stage of the post-yielding curve.

The properties of the steel liners are summarized as follows:

Density	ρ	=	7,850 kg/m ³
Young's Modulus:	E	=	203 x 10 ³ MPa
Poisson's Ratio:	ν	=	0.3
Yield Stress:	σ_y	=	370 MPa
Hardening Modulus:	E_t	=	1.5 x 10 ³ MPa

3.2 Concrete

The concrete used for the CIC is a specially designed high density mix. Information regarding the mechanical properties of high density concrete is almost non-existent. One reported test on high density concrete (Ref. 2) did not achieve the strength needed in the CIC program and hence its test data being considered unsuitable for use.

At the time of analyses, concrete tests were being undertaken at Ontario Hydro but data was not yet available. Some properties available from a previous test (Ref. 3) were therefore used and the adopted generic properties for computer input are:

Density:	ρ	=	3535 kg/m ³
Shear Modulus:	G	=	20 x 10 ³ MPa
Cutoff Pressure:	P_{min}	=	1.4 MPa

Two types of constitutive relations are required as the concrete is to be treated as a hydrodynamic material:

- a) A model to define the failure of the material (yield criterion)
- b) A model to describe the pressure-volume change relation (equation of state)

They are described in the following:

3.2.1 Yield Model

The yield strength of concrete has generally been based on the Mohr-Coulomb model as shown in Fig. 6. The criterion assumes that the material yields when its shear stress limit is reached. This is represented by a smooth curve tangent to the Mohr's circles of different tests including tension test, pure shear test, uniaxial and multi-axial tests. This implies that the concrete strength depends on its subjected normal stress state (i.e. hydrostatic pressure). In other words, the higher the confined pressure, the greater the compressive stress required to fail the material. This is because the higher confined pressure (which are the normal stresses) induces higher shear resistance which governs the yield condition.

To construct the current yield model, an inverse polynomial function with the following form is adopted:

$$\sigma_y^2 = a_0 + a_1 P \quad (1)$$

where σ_y is the concrete yield strength and P is the hydrostatic pressure which is mathematically represented by the negative average of the three normal stress components. The constants a_0 and a_1 are subsequently obtained based on the data from the two tests (compression and tension) reported in Ref. 3 and the resulting yield model is shown in Figure 7.

3.2.2 Equation of State

Similar to other granular materials, the equation of state for concrete possesses the form shown in Figure 8. When subjected to pressure, concrete initially responds elastically until it is crushed at point A. Then the concrete engages in aggregate compaction resulting in reduced stiffness. The complete compaction is achieved at point B and thereafter concrete regains approximately its original strength against compression. It is assumed that the concrete experiences elastic unloading should the pressure decrease in the post-crush stage. Furthermore, concrete's response to tension (i.e. negative pressure) is limited by its tensile strength. Once this limit is reached, concrete is assumed to be cracked and its ability to resist tension drops to zero.

Because no equation of state test has been performed for the concrete at the time of current analyses, the piecewise linear model shown in Figure 9 is proposed for the analyses. This model is based on past experience.

3.3 304L Stainless Steel

Stainless steel is used for the outer and inner skins of both impact limiters No. 1 and 2. A typical stress-strain curve based on Ref. 4 is replotted in Fig. 10 and indicates a linear strain hardening up to its final ductile fracture failure. The mechanical properties employed in the analyses are based on Ref. 4 as follows:

Density:	ρ	=	8,027 kg/m ³
Young's Modulus:	E	=	193 x 10 ³ MPa
Poisson's Ratio:	ν	=	0.28
Yield Stress:	σ_y	=	305 MPa
Hardening Modulus:	E_t	=	1.25 x 10 ³ MPa

3.4 Rigid Polyurethane Foam

Rigid polyurethane foam is used to absorb the energy during impact. Two types of foam identified as 17 lbs/ft³ and 15 lbs/ft³ density fill different portions of the impact limiter (see Fig. 3). At present, mechanical properties for these two foams are not available. One source of information (Ref. 5) dealt with foam of a different density and could not be used directly. The data in Ref. 5 was therefore modified to consider the density difference based on the following formula supplied by NED (Ref. 6):

$$\text{Property} = A (\text{Density})^B \quad (2)$$

where A and B are parameters for different types of properties. The resulting generic properties for computer input are:

Foam type #1 (17 lbs/ft³ density)

Density,	ρ	=	272 kg/m ³
Shear Modulus,	G	=	54.1 MPa
Cutoff Pressure	P _{min}	=	1.3 MPa

Foam type #2 (15 lbs/ft³ density)

Density,	ρ	=	240 kg/m ³
Shear Modulus,	G	=	47.4 MPa
Cutoff Pressure,	P _{min}	=	1.124 MPa

The required yield model (stress-pressure relation) and equation of state for the foams are reported in the following:

3.4.1 Yield Model

Similar to concrete, the yield models for the foams is constructed using an inverse polynomial function in accordance with Eq. 1. The test data of shear strength and tensile strength from Ref. 5 were adopted and modified following Eq. 2 to account for density difference. Based on these data, the constants a_0 and a_1 are calculated from Eq. 1 and resulted in the models as shown in Figure 11.

3.4.2 Equation of State

Equation of state possess a unique test which is different from those tests needed to generate yield stress-pressure relation. This constitutive law relates the volume strain of the foam specimen to its subjected hydrostatic pressure. Because no test has been performed at the time of analysis, previous test data (Ref. 5) were adopted and modified. The tests data were firstly converted from engineering stress/strain to true stress/strain and had already been done previously (e.g. Ref. 7). However the tests were conducted in uniaxial compression using disc-type specimen with various diameters to simulate lateral restraint for a multi-stress state (3D). It is judged that the poisson's effect has not been fully considered which would result in the actual volume strain being less than the recorded uniaxial strain. This means that the equation of state based on the uniaxial test data is conservative. On the other hand, it is rather difficult to evaluate volume strain from uniaxial tests data while the poisson's ratio of the foam is not known and the foam experienced a complete stress history from elastic to plastic. Consequently, the volume strain is assumed to be one-half of the uniaxial strain and results in the currently used equation of state as shown in Fig. 12. Due to the above described uncertainty, it is felt that there is no point to adopt two separate curves for the 15 lbs/ft³ and 17 lbs/ft³ foams respectively and hence one curve is used for both foams. It should be noted that the same equation of state is used for all three drop orientations and hence comparison will be on the same ground.

4.0 FINITE ELEMENT MODELLING

The CIC structural system is transformed into a mathematical model through the interactive engineering software PATRAN. As the finite element technique will be applied in the analyses, the CIC steel liners and the impact limiter stainless steel skins are simulated by four-noded shell elements while the concrete, the rigid polyurethane foam, the payload and the rigid ground by eight-noded solids. PATRAN, functioning as a pre-processor, creates these elements and generates a set of input data for later analyses. Because the configuration of the system is rectangular in shape and hence lost its advantage of symmetry, the entire structure of the CIC system is modelled. Actually the finite element modelling for the three analyses are very

similar and hence details will only be described for the drop orientation Case 1. For Cases 2 and 3, only those differences in modelling from Case 1 will be pointed out.

4.1 Case 1: C.G. Directly Above the Impact Point

Fig. 13 presents the shell element mesh for the stainless steel skin of the impact limiter #1 with a bottom/front view and a top/rear view. The impact region is modelled by a refined mesh in order to obtain more accurate result at that area. The refinement is gradually reduced for the region farther away from the impact location for economy of computing cost. A complete solid element modelling of the rigid polyurethane foam for the entire impact limiter #1 is illustrated in Fig. 14.

The lid of the container possess a self-enclosed steel covering box which is simulated by shell elements as shown in Fig. 15. Again, a bottom/front view and a top/rear view are provided. The filled concrete is modelled as demonstrated in Fig. 16. Note that pattern of the mesh generated for concrete is identical to that of the steel lid plates while the concrete is divided into four layers of solid elements through the thickness.

The corresponding two views of shell element mesh for the outer liner of the container itself are provided in Fig. 17. Fig. 18 illustrates the generated mesh for the inner liner of the container. Physically, the lid and container are seal-welded together along their exterior perimeter at contact. This is simulated by rigidly tying the two corresponding nodes at the same position at lid and container together. Fig. 19 shows the solid element mesh for the container concrete. The payload is modelled by solid elements as shown in Fig. 20. It is crudely modelled with the prime purpose of accounting for its mass in the analyses.

Fig. 21 illustrates the shell element mesh for the skins of the impact limiter #2. Because this limiter is far away from the impact point, its effect and response is expected to be less significant. A crude simulation is judged adequate. Similarly, a crude solid element simulation for the rigid polyurethane foam within the impact limiter #2 is shown in Fig. 22.

The shell elements simulating the steel liners and limiter skins of the entire CIC system is illustrated in Fig. 23. Fig. 24 is created to provide a physical feeling for the complete solid element mesh including foam, concrete and rigid ground. Finally a schematic finite element model of the system in colour-filled form is demonstrated in Fig. 25. The rigid ground is modelled by solid elements and is restrained from movement.

4.2 Case 2: 5° Tilted Vertical Drop

The finite element modelling for this case is essentially identical to that of Case 1. The minor revision of extending the refined mesh a little farther toward the remote area is primarily for the purpose of improving the smoothness of the numerical analysis. From a geometrical modelling point of view, this small improvement in mesh is rather insignificant when compared to that of the entire system. The final schematic element model is demonstrated in Fig. 26.

4.3 Case 3: 5° Tilted Horizontal Corner Edge Drop

The finite element modelling for this case is also identical to that of Case 1 except the modelling of impact limiter #2. This impact limiter is originally tilted five degrees with respect to the initial impact point but eventually will hit the rigid ground at a later time and then start to share the energy absorption capacity with impact limiter #1. For this reason, the impact limiter #2 is moderately refined from that of Case 1. Figs. 27 and 28 show the revised shell element mesh for the skins and solid element mesh for the rigid polyurethane foam respectively. The subsequent shell element and solid element meshes of the entire CIC systems are demonstrated in Figs. 29 and 30 respectively. A final schematic illustration of the finite element model for this case is presented in Fig. 31.

5.0 ANALYTICAL RESULTS AND DISCUSSION OF IMPACT RESPONSES

The CIC system is assumed to undergo a nine (9) meter top-down corner drop with three different angles. The formal stress analyses are carried out using the Ontario Hydro version of the hydrodynamic code DYNA3D (Ref. 8), an explicit three dimensional finite element code for analyzing the large deformation dynamic response of inelastic solids and structures. The analytical data is then fed back to PATRAN for post-processing. With its colour graphic capability, PATRAN sorts, interprets, summarizes and presents the resulting data in suitable forms.

The results are reported and discussed in terms of energy, momentum, contact force, deformation, stress and strain. In stress and strain, the von Mises stress is used to express the multi-stress state experienced in the CIC for simplicity and clarity. For the cases of non-metallic material (concrete and rigid foam) where the tensile strength is significantly different (i.e. less) from the compressive strength, hydrostatic pressure is supplemented to report the normal stress state of the material. All the stresses reported in the figures are in units of MPa.

It should be noted that stresses are stored at a chosen time interval and only the critical stress at critical times are reported. This usually occurs around (but not necessarily exactly) the time of peak contact force. Furthermore, the stresses for the shell elements (i.e. stainless steel skin of impact limiter and the mild steel liners of CIC) were recorded at the inner, middle and outer surfaces of the steel plate. However, because it is dominated by membrane stress, differences at different surfaces due to bending are usually small and insignificant. Therefore, the stress at only one face is considered adequate for presentation and comparison. The equivalent plastic strain is presented to provide a means to evaluate the degree of damage at any part of the CIC system.

For clarity, components of the system, (namely impact limiter #1, the lid, the container itself and impact limiter #2) are presented separately. Each component is further divided into two parts representing different materials (i.e. mild steel/stainless steel and concrete/foam).

In this section, results and responses are given for each drop orientation individually. Comparison among the three different orientations will be investigated in the next section.

5.1 Case 1: C.G. Directly Above the Initial Impact Point

Figs. 32 and 33, respectively, are the plots of the kinetic energy time history and the normalized momentum time history of the CIC system during the course of impact. Both figures identify the full stop of the CIC at approximately 0.095 seconds after initial contact and a rebound thereafter. The smoothness of these curves implies a stable numerical analysis being experienced.

Figs. 34 provides an impact force time history plot expressed in units of Newton's and g's. This is the total contact force between impact limiter #1 and the rigid surface throughout the entire impact. It is seen that the maximum of approximate 26.5g occurs at approximately 0.084 seconds.

Fig. 35 presents a series of system deformation plots at a 0.02 second time interval to provide an equivalent animation. Obviously, the most damage occurs at the impact limiter #1 and, based on computer output data, the deformation footprint size is evaluated as shown in Fig. 36. It is noted that the top and inner stainless skin hold the rigid polyurethane foam effectively with significantly less deformation when compared to that of the bottom portion of the limiter. Deformation on the other components of the CIC system (i.e. the lid, container and impact limiter #2) is not noticeable since they remain essentially elastic with insignificant permanent (plastic) deformation. Deformation of the CIC system will be examined more closely in the following along with the presentation of stress and strain distribution.

Figs. 37, 38 and 39 provide sequential bottom, front and top views of von Mises stress distribution at the impact limiter #1 stainless steel skin at 0.08 second. It is interesting to note (Fig. 37) that the outer skin is buckled into two folds with the highest stress (687 MPa) occurring at the tip of the folds where the steel plate experienced the largest stretching and curvature change. It is also noted that stress at the inner skin (Fig. 39) is significantly less than that of the outer skin (about one half). However, both outer and inner skin around the impact region (approximately one-quarter of the entire impact limiter) has yielded.

The accumulated total plastic strain in the stainless steel skin at 0.10 second is illustrated in Fig. 40. The analysis indicates that there is no further permanent damage since 0.08 second as the entire CIC system is experiencing elastic unloading thereafter.

The von Mises stress distribution in the rigid polyurethane foam follows a pattern similar to that of the stainless steel skin. Two views at 0.08 second are presented in Figs. 41 and 42. Higher stress at the inner face of foam (Fig. 42) occurs at the location corresponding to the corners of the CIC and is due to the CIC/impact limiter interface contact during impact.

The normal stresses in the foam are demonstrated in terms of hydrostatic pressure in Fig. 43. It indicates that the area under direct contact (i.e. tip) is subjected to the highest pressure (note that the negative value indicates compressive stress) as it should be. The rest of the foam has its compressive stress gradually reduced to zero or even tensile due to elastic lateral expansion of the material body (Poisson's effect).

The von Mises stress distribution at the cover plates of the lid is shown in Figs. 44 (0.08 second) and 45 (0.10 second). The maximum stress of 267 MPa is below the yield strength of 370 MPa. It is interesting to note that the higher stresses arrive at one corner earlier than the other corner. This is due to nonsymmetry of the structure (compare the dimension 2.418m against 2.110m in Fig. 2) which may cause the CIC to contact the impact limiter at one corner earlier than the other. Furthermore, the vertical plate at the side of 2.418m possesses a larger aspect ratio than the plate at the other side of 2.110m and hence is more flexible (weaker). It therefore tends to yield first and then have the stress redistributed to the other side.

Fig. 46 presents the accumulated plastic strain in the lid plate. It is seen that the lid plate only experiences a very small amount of plastic strain (about 2%) at a small localized area. The majority of the lid remains elastic throughout the entire course of impact.

The response of the lid concrete follows the similar pattern of steel plate. Von Mises stress distribution of two selected views at 0.08 second and 0.10 second are shown in Figs. 47 and 48 respectively. The accumulated plastic strain is illustrated in Fig. 49, which identifies the location and size of concrete being failed. Fig. 50 demonstrates the magnitude of hydrostatic pressure in concrete.

The highest von Mises stress in the container outer liner is shown in Fig. 51 at 0.08 second. The stress remains at a relatively low level. Stress in the inner liner is even less significant. Because the entire liner remains elastic throughout the impact course, no plastic strain is recorded.

Stress in the container concrete is selectively shown in Fig. 52 and also remains at a relatively low level. The only recorded plastic strain in the concrete is an extreme small amount with no physical significance. Practically the container responds elastically throughout the impact. The hydrostatic pressure in the concrete is presented in Fig. 53 (at 0.08 second).

Stress and strain in the impact limiter #2 are very small and insignificant. Their presentations are therefore omitted.

5.2 Case 2: 5° Tilted Vertical Corner Drop

Figs. 54 and 55 are the kinetic energy and normalized momentum time history plots respectively. Computation is terminated at 0.04 second as the figures demonstrate clearly that the CIC system has reached its full stop at that time. Fig. 56 provides the contact force time history in the unit of Newton's and g's. The average maximum force is approximately 57g at about 0.03 second after initial contact. Fig. 57 provides an equivalent animation of the impact.

A closer examination at the impact limiter #1 with the evaluated footprint size is shown in Fig. 58. It can be seen that the impact limiter outer skin has buckled; however, the vertical deformation of the limiter is not as severe as Case 1 because the impact force is distributed to a much larger contact area in this case. More details of deformation will be illustrated later along with stress and strain presentation. Deformation of the CIC itself and the impact limiter #2 are insignificant and hence their presentation is omitted.

Following the same presentation format as in Case 1, the von Mises stress in the impact limiter #1 stainless steel skin is shown with two different views in Figs. 59 and 60 respectively. The highest recorded stress is 580 MPa. One very interesting observation is shown in Fig. 61 which identifies a clear indent on the horizontal inner skin plate hit by the CIC.

Plastic strain in the impact limiter outer skin is reported in Fig. 62 identifying the degree of damage. Damage at the inner skin is relatively minor. There is eventually no further growth of plastic strain after 0.03 second.

Stress in the foam is covered by Figs. 63 and 64 with two views of bottom and top to show the outer and inner face of the foam with the highest stress being experienced. Hydrostatic pressure is reported in Fig. 65 and is small due to a larger contact area with target pad.

Stress in the lid cover plate is shown in Figs. 66 and 67. The maximum stress increased from 273 MPa at 0.02 second to 329 MPa at 0.03 second and then reduced to 314 MPa at 0.04 second. Fig. 68 illustrates the accumulated plastic strain in the lid plate. In any case, the cover plate behaviour remains largely elastic with a minimum amount of yielding at a very localized area.

The highest stress in the lid concrete is illustrated in Fig. 69 while the total plastic strain is recorded in Fig. 70. Hydrostatic pressure is demonstrated in Fig. 71, where the localized high pressure areas indicate the areas subjected to higher compressive stress due to contact with impact limiter and compression by the bending of the covering steel plate. The response of the lid is generally similar to that of Case 1 which has been discussed previously.

The highest stress in the outer liner of the container is shown in Fig. 72. Only very minor yielding is observed with the total accumulated plastic strain being about 0.1% and is rather insignificant. Stress in the inner liner is further lower and remains elastic.

The highest container concrete stress is presented in Fig. 73 and is below the ultimate crush strength of 40 MPa. The recorded plastic strain occurs at a few spots only and are small (0.07%). They are of little practical significance. The hydrostatic pressure is demonstrated in Fig. 74.

Similar to Case 1, impact limiter #2 experiences little stress and strain and hence is not reported.

5.3 Case 3: 5° Tilted Horizontal Corner Edge Drop

The system kinetic energy and normalized momentum time histories in this case are plotted in Figs. 75 and 76 respectively. The contact force in units of Newton's and g's are presented separately for impact limiter

#1 and #2 in Figs. 77 and 78. It is seen that the peak force is about 19g for limiter #1 and 17g for #2. Adding the two together, the peak total contact force would be about 36g. It is also noted that the time lag for the impact limiter #2 to hit the rigid ground is about 0.025 second.

Similar to the previous two cases, Fig. 79 provides an equivalent animation and it is interesting to note that the impact limiter #2 is gradually tilting toward limiter #1 during the impact. The deformation of impact limiter #1 with its evaluated footprint size due to damage is reported in Fig. 80. A closer examination of deformation shows that the longer side (i.e. the weaker side as discussed in Case 1) buckled into a double wave form. Deformation in the impact limiter #2 is less severe than that of limiter #1 and is shown along with its damage size in Fig. 81. The tendency to buckle into a wave form is quite noticeable in the figure.

Von Mises stress in the impact limiter #1 stainless steel skin is presented in Figs. 82 and 83. It is interesting to note that the higher stress occurs at bottom, middle-height and top corners since those are the areas being physically stiffened by the horizontal bottom, inner and top skin plates of the limiter. Fig. 84 provides accumulated total plastic strain which actually ceased to grow after 0.04 second.

The stress in the rigid foam of impact limiter #1 is illustrated in Fig. 85. It is interesting to note that higher von Mises stress occurs at the top (projection) portion of the limiter. The hydrostatic pressure is plotted in Fig. 86. Higher pressure occurs at the mid-height location as this area is compressed due to contact with the target from outside and with the CIC from inside.

Von Mises stress in the lid cover plate is demonstrated in Fig. 87 and remains relatively low. The only recorded permanent damage has an accumulated plastic strain less than 2% (Fig. 88). Response of the concrete inside the lid is similar to that of the previous two cases with moderate stress level (Fig. 89) and minimum damage (Fig. 90). The hydrostatic pressure is illustrated in Fig. 91.

The stress in the outer liner of the container is shown in Fig. 92. It is noted that higher stress occurs at the top end because the top end is under direct impact of limiter #2 while the lower end is connected to the lid and is not under the direct impact of limiter #1. However, this stress difference does not have much physical significance as, most importantly, the entire liner stays elastic throughout impact and no plastic deformation is experienced.

Stress in the container concrete is recorded as shown in Figs. 93 and 94. A comparatively larger area with higher stress occurs at the top end due to the impact limiter #2 as mentioned earlier. Essentially the concrete remains at a relatively low stress level without damage. The plastic strain at the level of 0.055% is rather negligible. The hydrostatic pressure in the concrete is reported in Fig. 95 which indicates that compression is experienced at both ends with higher pressure at the top due to the previously referred reason.

Von Mises stress in the impact limiter #2 stainless steel is reported in Fig. 96. Significantly higher stress at the damaged area is evident. The total plastic strain accumulated in the skin is plotted in Fig. 97 which indicates that the damage is significant but within its ductile limit.

The von Mises stress and hydrostatic pressure in the rigid foam of the impact limiter #2 are shown in Figs. 98 and 99 respectively. They all show a similar pattern with the highest response occurring at the most damaged area.

6.0 COMPARISON OF THE THREE CASES

The results discussed in the previous section are summarized in Table 1 where the maximum contact force, damage, stress and strain are listed for comparison. It should be reiterated that the comparison should be

qualitative rather than quantitative. The comparisons are made for the impact limiter #1, the container itself and the impact limiter #2.

6.1 Impact Limiter #1

Table 1 indicates that the contact force in Cases 1 and 3 are about the same order while that in Case 2 is approximately two times higher. This implies that the Case 1 and Case 3 are relatively softer compared to Case 2.

It can also be seen that Case 1 suffers the most severe damage. Case 3 also experienced critical damage even though the deformation area is smaller due to the fact that the impact limiter skin plates provide more effective restraint to the foam from lateral movement because of its drop orientation. The damage in Case 2 is the least severe.

The various stress and strain components in the limiter skin and the rigid foam consistently demonstrate that the highest level occurs in Case 3, the second highest in Case 1 and the least in Case 2. Case 3 is higher than Case 1 due to higher stress concentration within a smaller deformed area.

In conclusion, the impact limiter #1 suffers more damage in Case 1 and 3 than Case 2. Comparing Case 1 and 3, Case 1 has a lower stress distributed in a larger deformed area while Case 3 has higher stress concentrated in a smaller deformed region.

6.2 CIC

There is no noticeable deformation or damage in the CIC itself for all three cases.

In terms of stress and strain, Case 3 appears to be the lowest and hence the least critical. Further comparison between Cases 1 and 2 indicates that Case 1 possess lower stress in steel, approximately same level of concrete stress and higher hydrostatic pressure than that in Case 2. Overall, Case 2 experienced slightly higher stress and strain than Case 1. However, it should be noted that the comparison based only on the peak value at a given instant of time while the CIC remains virtually elastic throughout impact for both cases.

On the other hand, when visualizing the entire structural system globally, Case 2 which is a vertical drop will have the lid to transfer impact force to the container through direct contact as a compressive force between the two structural bodies. Whereas, in Case 1, where the CIC is greatly tilted, the lid will transfer impact force to container partially by compression and partially by shear. This means that the lid has to transfer the shear force to the container through their connection at closure seal weld and hence is subjected to a possible shear failure.

In conclusion, Case 1 is more vulnerable to shear failure at CIC closure while Case 2 possess higher peak stress. Case 3 is the least critical.

6.3 Impact Limiter #2

Stress and strain in impact limiter #2 for the Case 1 and 2 are small and insignificant. Only in Case 3, the limiter experiences severe damage with significant contact force, stress and strain.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Impact analyses based on the top-down orientation of 1) C.G. directly above the initial impact point, 2) 5° vertically tilted drop and 3) 5° horizontally tilted corner edge drop have been performed. Due to the uncertainty of material properties of the rigid foam and concrete, results are studied qualitatively for comparison purpose instead of in quantitative terms.

Even though the response of the impact limiter is discussed in this report because that is where the major action and damage has taken place, the primary purpose of these analyses is still to decide the critical drop orientation causing maximum damage to the container itself. With this objective, the analyses conclude that the drop orientation of Case 1 and 2 are recommended for drop tests. Case 1 is recommended with higher priority because it is vulnerable to lid/container closure failure. Furthermore, this orientation of C.G. above impact point has historically been chosen for drop tests of various kinds of industrial and nuclear waste containers. Its importance is obvious and this orientation should be carried out in the current CIC tests. Case 2 is also recommended because it might generate higher peak stress in the CIC.

It is worthwhile to note that the stress/strain in the container remains in the elastic range throughout impact with a very limited area experiencing yielding. Even in these yield areas, the plastic strains remain at a minimum level without much practical significance. Furthermore, there is no visible permanent deformation in the container. It is therefore predicted that there will be no damage in the container in the drop tests.

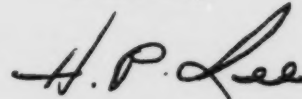
On the other hand, Case 3 does generate higher stress/strain than the other two cases in the impact limiter. A drop orientation similar to Case 3 would be of interest to study the impact limiter itself.

Reviewed by:



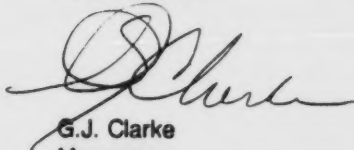
T.P. Byrne
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Engineer
Applied Mechanics Section

Approved by:



G.J. Clarke
Manager
Mechanical Research Department

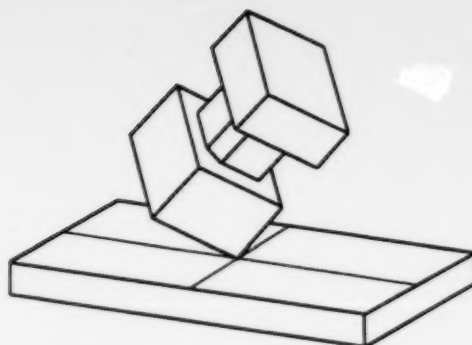
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REFERENCES

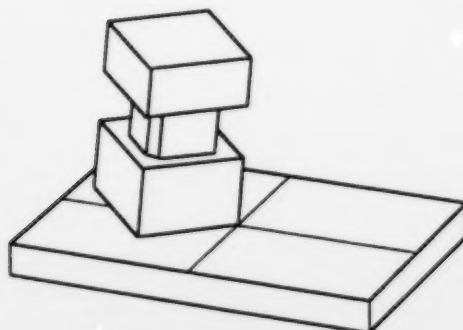
1. "CIC-Material Property Test Results at Room Temperature and -40°C for CSA G40.21 300WT & CSA G40.21 300WT Category 4", Memo from S.A. Reid to R.N. Sumar, January 6, 1989, File: 967-TRAN-03453.04P, 967- TRAN-03722.04P, and 825.122(T), Ontario Hydro.
2. Raju, N., Krishna, "Properties of High Density Concrete", Indian Concrete Journal, V.58, n5, p130-133, May 1984.
3. Sato, J.A., and Andre, H., "Concrete Integrated Container (CIC) Program, Construction of 1/4 and 1/8 Scale Models", Ontario Hydro Research Division Report 88-97-K, May 1988.
4. Conway, J.B., Stentz, R.H., and Berling, J.T., "Fatigue, Tensile and Relaxation Behaviour of Stainless Steels", TID-26135, Technical Information Centre, Office of Information Services, United States Atomic Energy Commission, 1975.
5. Black, D.A., "Mechanical Properties of Polyurethane Foam for Tritiated Heavy Water Transportation Package", Ontario Hydro Research Report B84- 99-H, November 1984.
6. Smith, S.M., "Relevant Material Properties for CIC Impact Limiter Modelling", Notes, Nuclear Engineering Department, Ontario Hydro, July 25, 1988 (Rev. 0), December 6, 1988 (Rev. 1).
7. Sauvé, R.G., and Morandin, G.D., "Tritiated Heavy Water Transportation Package: Analytical Assessment of Fluid-Structure Interaction Effects During Impact", Ontario Hydro Research Division Report 88-208-K, November 1988.
8. Sauvé, R.G., "Ontario Hydro DYNA3D Computer Code System VAX/VMS Version", Ontario Hydro Report No. 87222, November 1987.

TABLE 1: COMPARISON OF THREE DROP ORIENTATIONS

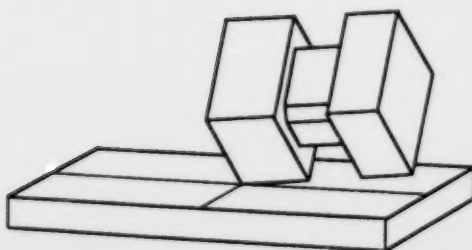
CASE			CASE 1 C.G. Above Impact Point	CASE 2 Vertically 5° Tilted	CASE 3 5° Horizontally Tilted
ITEM					
CONTACT FORCE			Limiter 1: 26.5g Limiter 2: 0 TOTAL: 26.5g	Limiter 1: 57g Limiter 2: 0 TOTAL: 57g	Limiter 1: 19g Limiter 2: 17g TOTAL: 36g
Limiter #1	Deformation (Damage)		Most Severe	Minor	Severe
	S.S. Skin	Effective stress Plastic strain	687 MPa .332	580 MPa .234	781 MPa .439
	Rigid Foam	Effective stress Hydrostatic pressure	4.28 MPa -8.28 MPa	4.02 MPa -6.45 MPa	7.3 MPa -17.1 MPa
Lid	Steel Cover	Effective stress Plastic strain	267 MPa .0225	329 MPa .0261	212 MPa .0186
	Concrete	Effective stress Plastic strain Hydrostatic pressure	33.9 MPa .0148 -24.8 MPa	34.3 MPa .0192 -17.0 MPa	37.1 MPa .0123 -31.4 MPa
Con- tainer	Steel Liner	Effective stress Plastic strain	192 MPa 0.	276 MPa .00116	205 MPa 0.
	Concrete	Effective stress Plastic strain Hydrostatic pressure	29.0 MPa .00035 -9.25 MPa	35.5 MPa .000733 -10.4 MPa	14.2 MPa .000558 -6.28 MPa
Limiter #2	S.S. Skin	Effective stress Plastic strain	--- ---	--- ---	589 MPa .353
	Rigid Foam	Effective stress Hydrostatic pressure	--- ---	--- ---	7.21 MPa -9.7 MPa



Case 1: C.G. Directly Above Impact Point

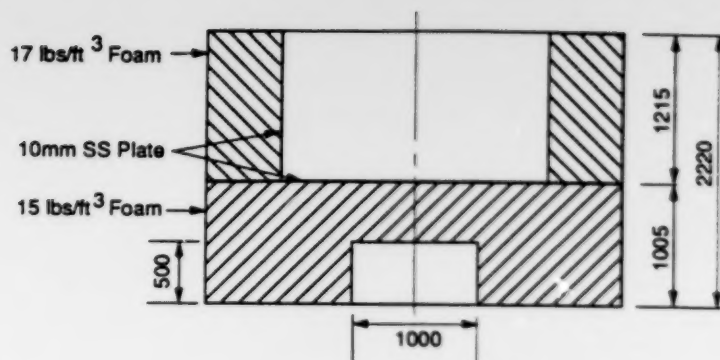


Case 2: 5° Tilted Vertical Prop

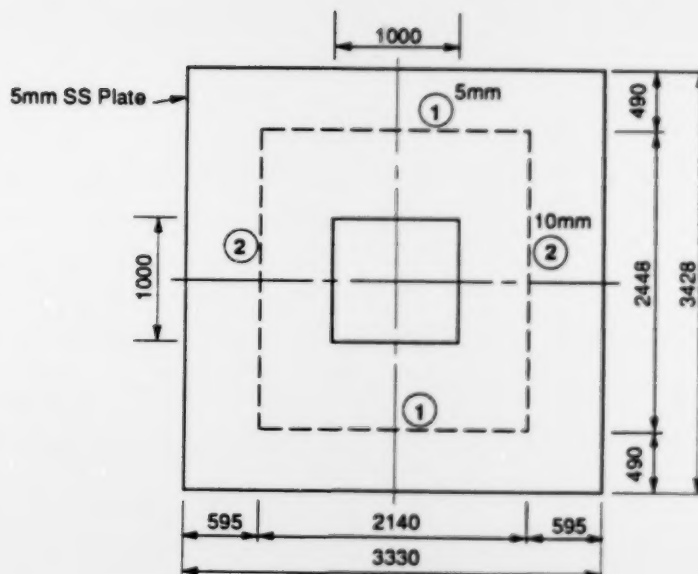


Case 3: 5° Tilted Horizontal Drop

FIGURE 1
DROP OPERATIONS



(a) Section View



(b) Plane View

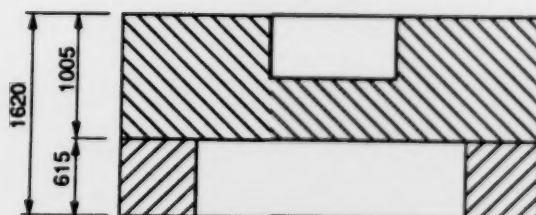
Note:

Plate ① 5 mm

Plate ② 10mm

FIGURE 3

CONFIGURATION OF IMPACT LIMITER NO. 1



Section View

FIGURE 4

CONFIGURATION OF IMPACT LIMITER NO. 2

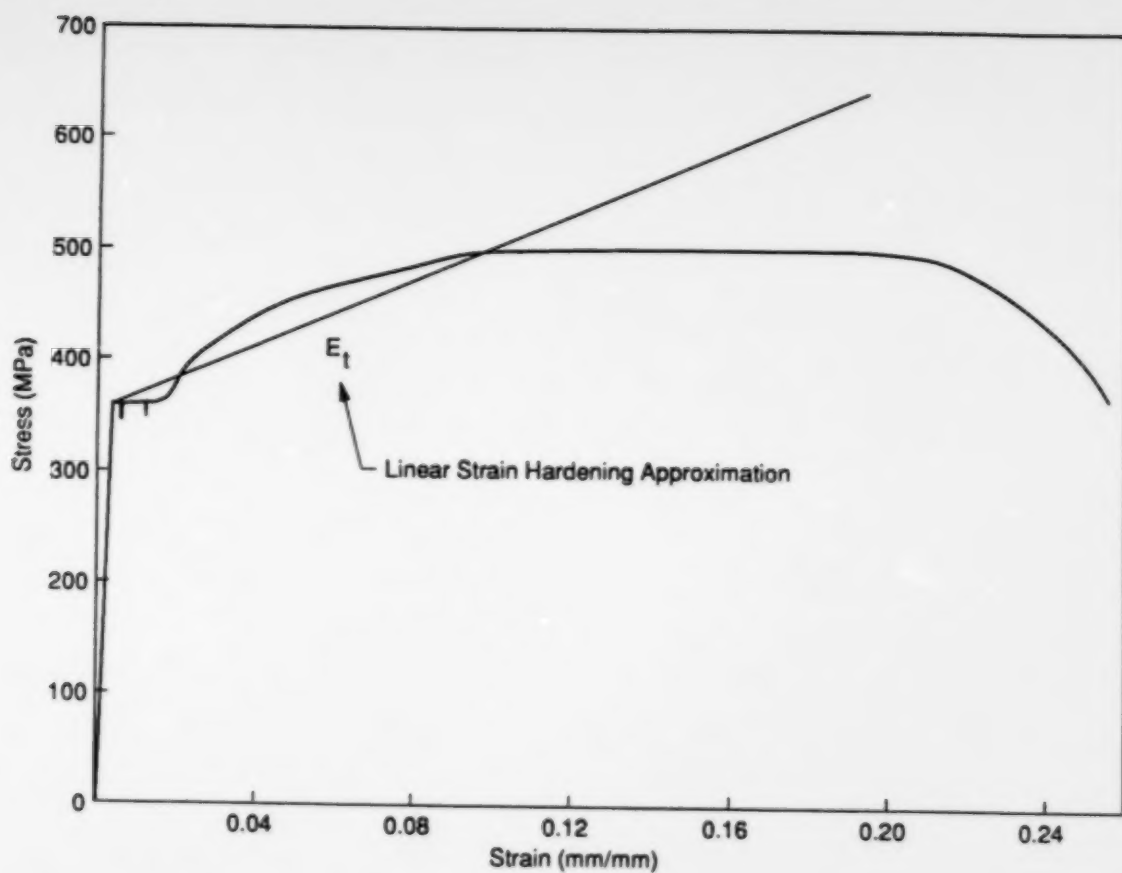


FIGURE 5
STRESS-STRAIN RELATION OF CSA G40.21 300 WT STEEL

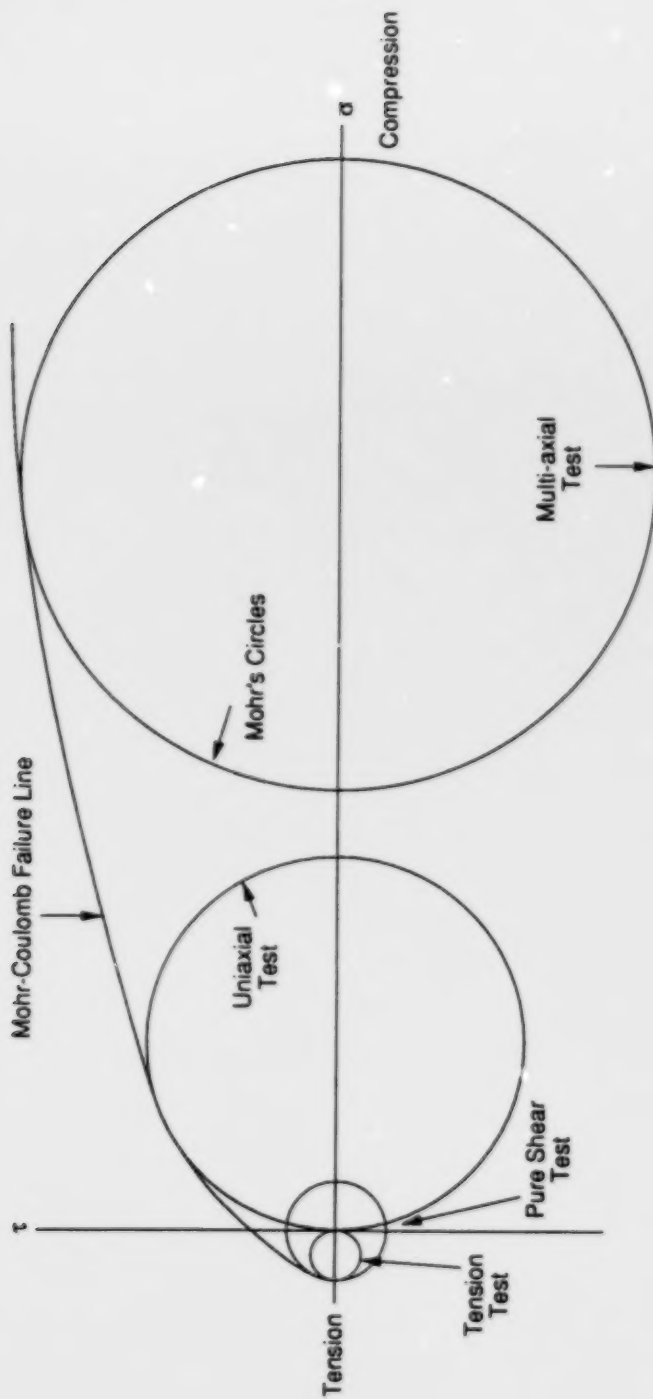


FIGURE 6
MOHR-COULOMB FAILURE LAW

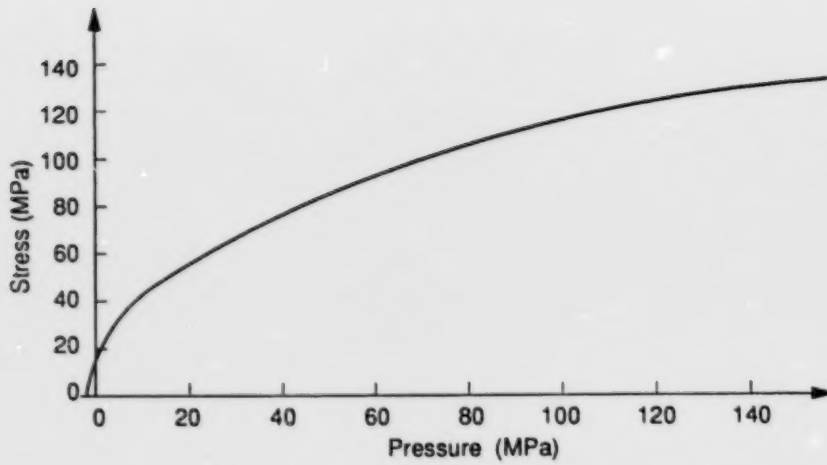


FIGURE 7
YIELD STRESS-PRESSURE RELATION OF CONCRETE

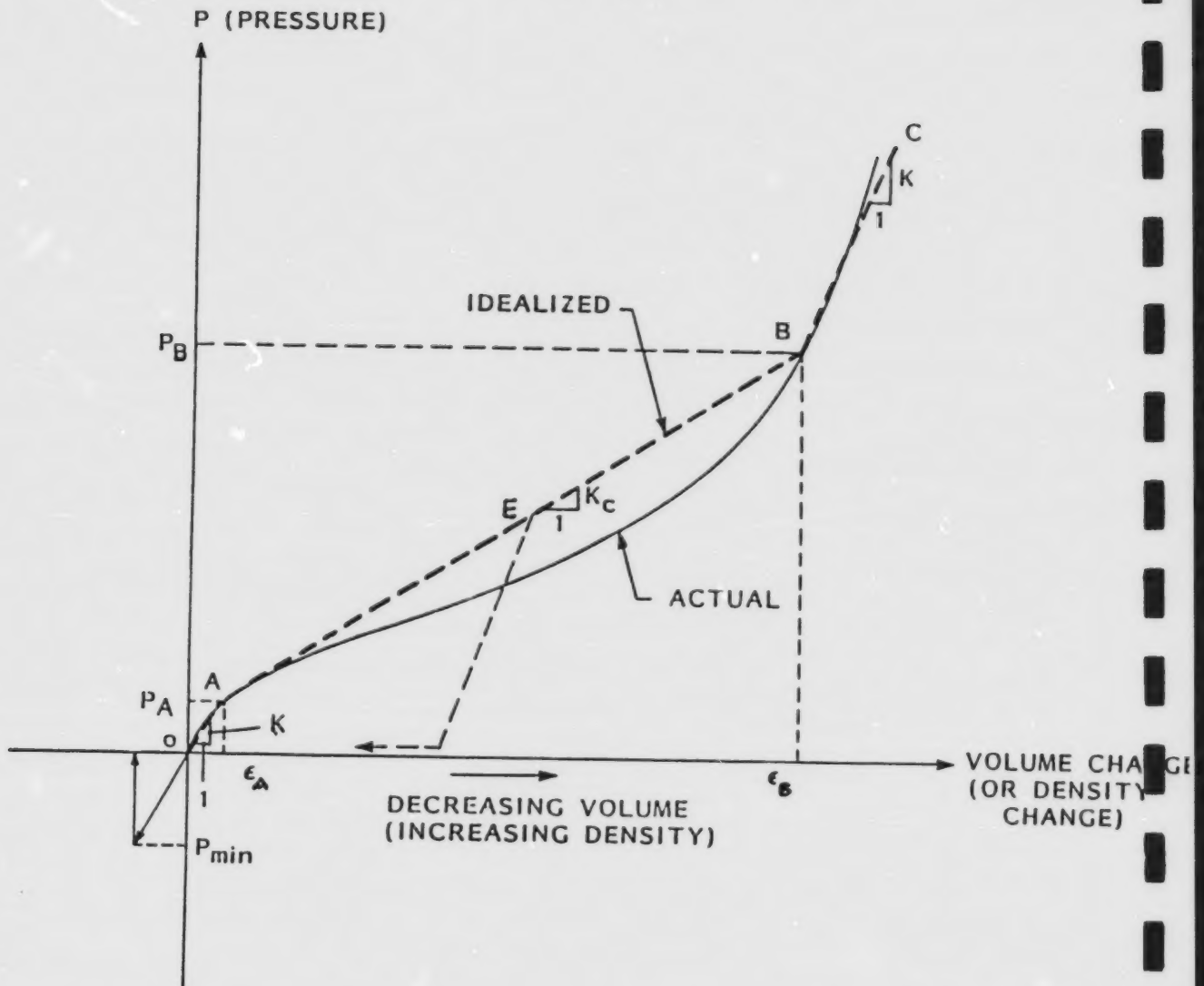


FIGURE 8
TYPICAL EQUATION OF STATE CURVE FOR GRANULAR MATERIALS

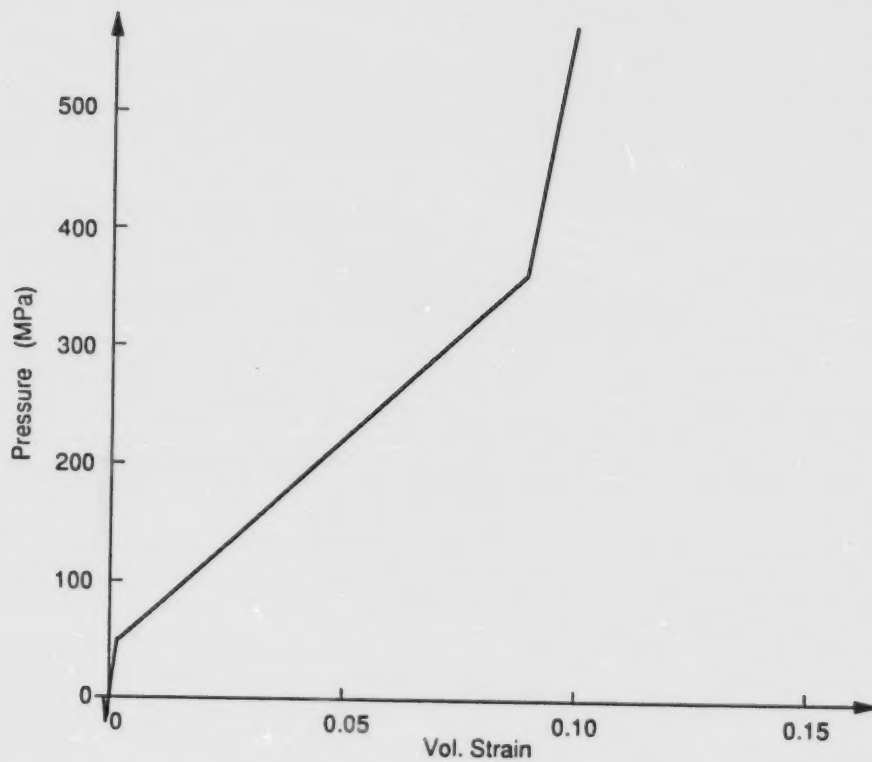


FIGURE 9
EQUATION OF STATE MODEL FOR CONCRETE

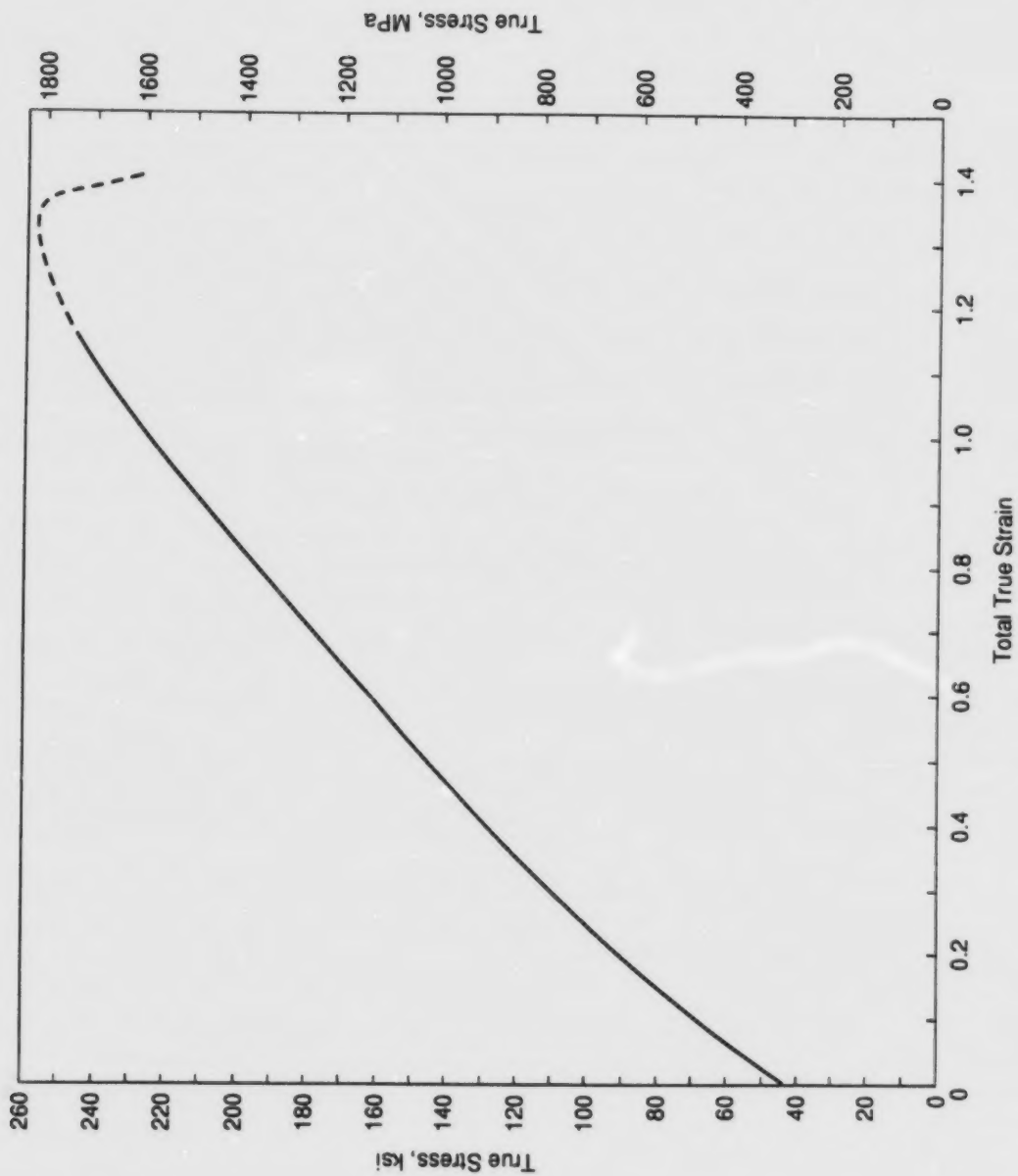


FIGURE 10
STRESS-STRAIN RELATION OF 304L STAINLESS STEEL

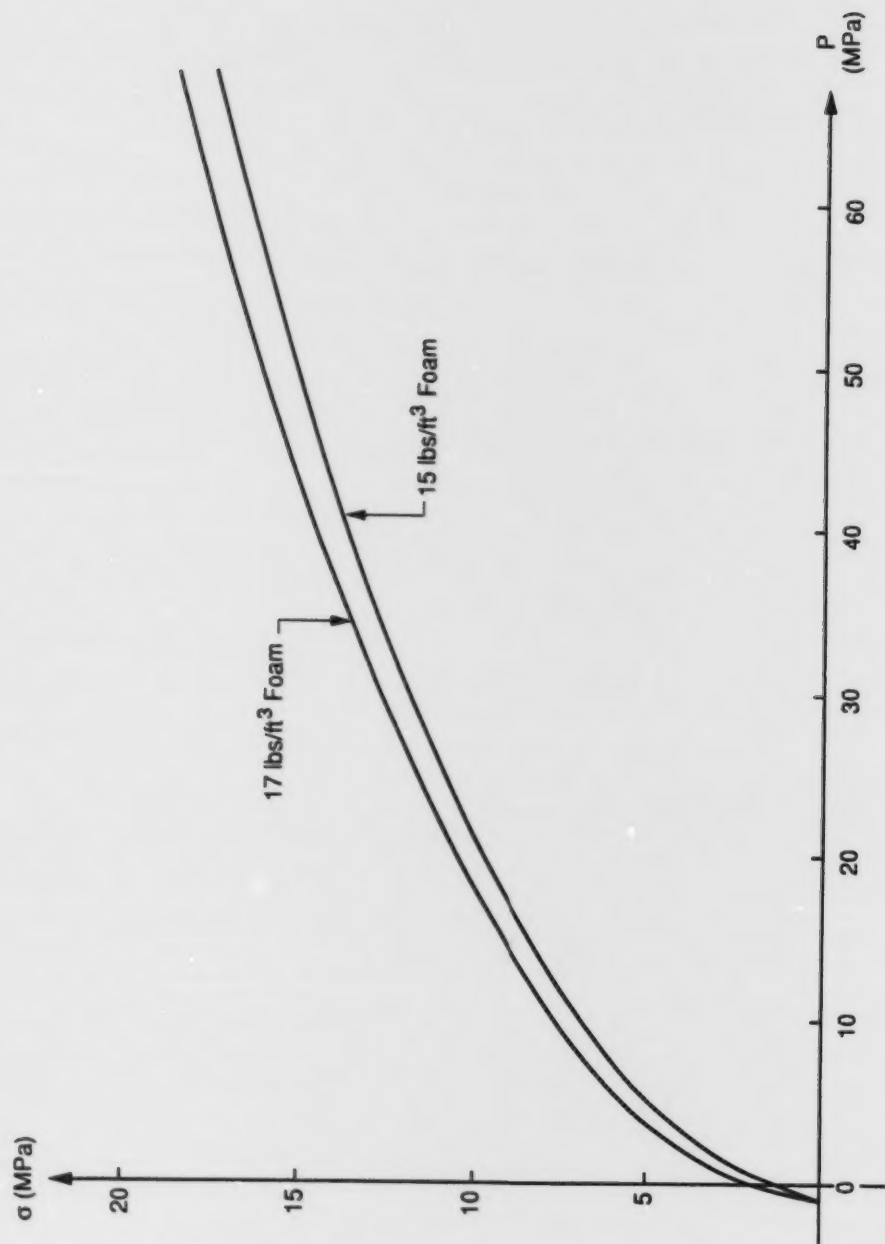


FIGURE 11

YIELD STRESS - PRESSURE RELATION OF THE RIGID POLYURETHANE FOAMS

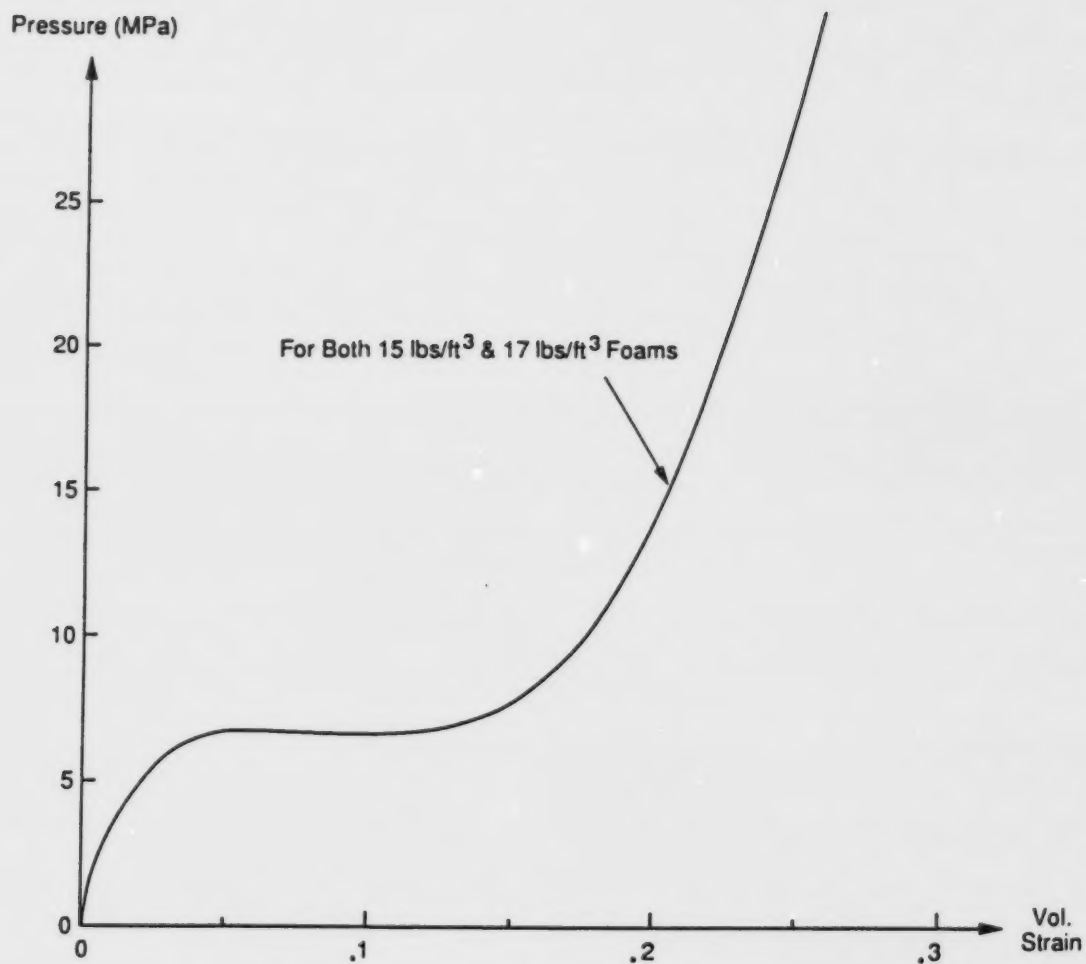
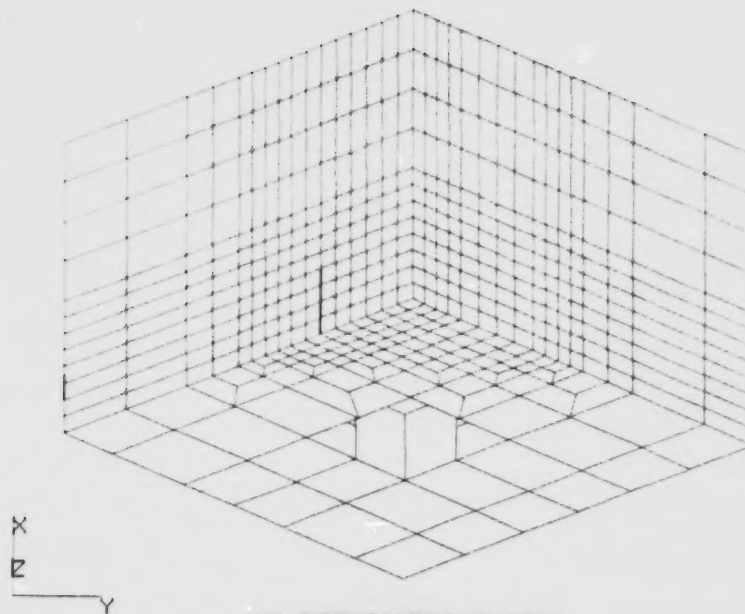
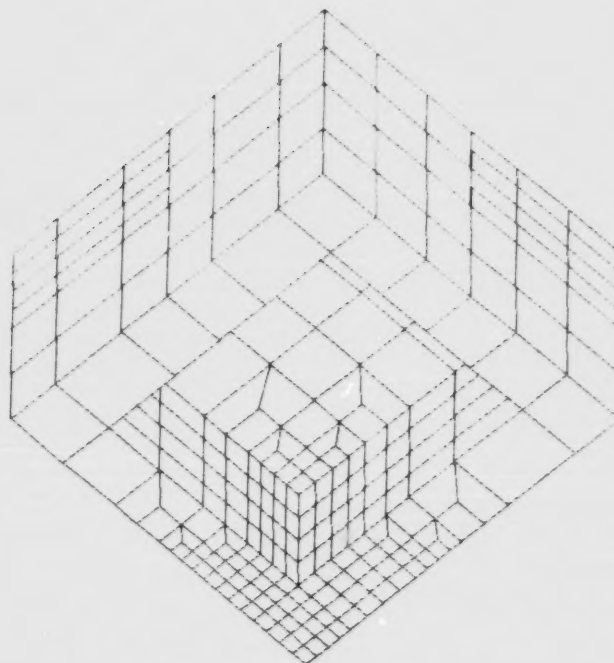


FIGURE 12
EQUATION OF STATE MODEL FOR THE RIGID POLYURETHANE FOAMS



(A) BOTTOM/FRONT VIEW



(B) TOP/REAR VIEW

FIGURE 13

**CASE 1: SHELL ELEMENTS FOR THE STAINLESS STEEL SKINS OF
THE IMPACT LIMITER #1**

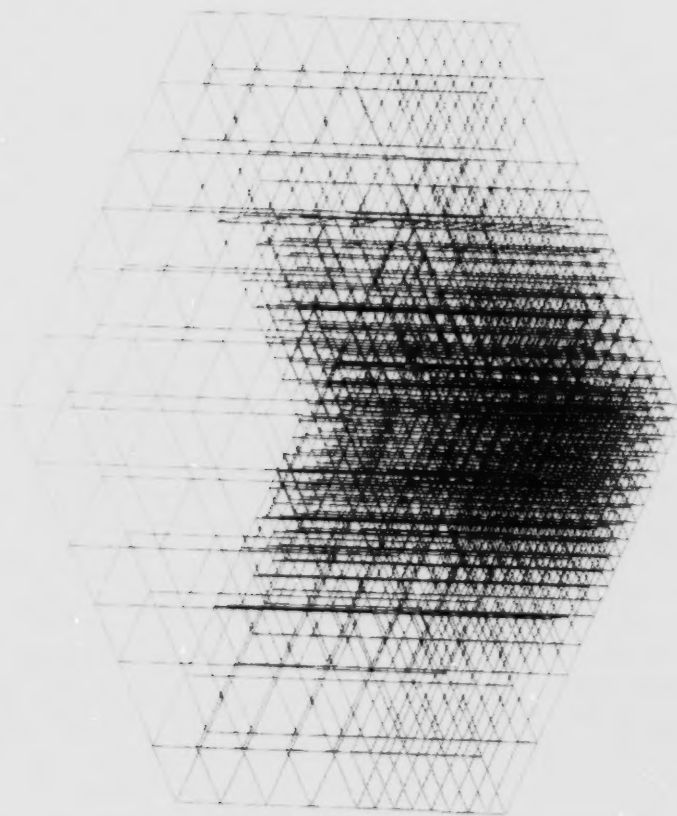
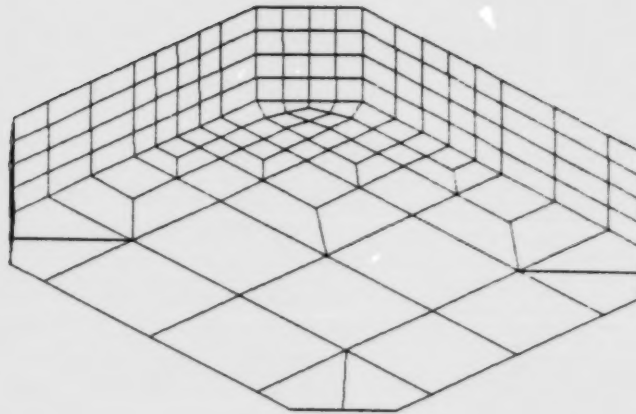
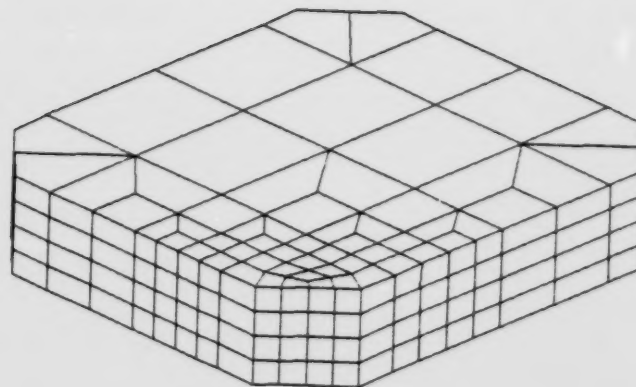
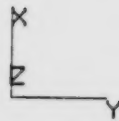


FIGURE 14

**CASE 1: SOLID ELEMENTS FOR THE RIGID POLYURETHANE
FOAM IN THE IMPACT LIMITER #1**



(A) BOTTOM/FRONT VIEW



(B) TOP/REAR VIEW

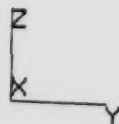


FIGURE 15

CASE 1: SHELL ELEMENTS FOR THE CIC LID PLATES

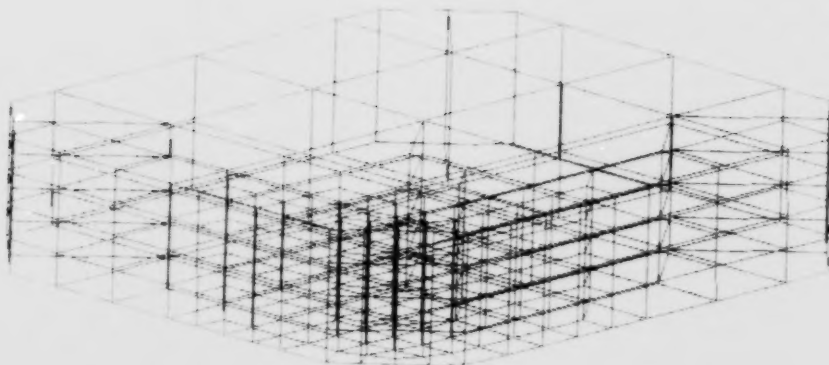
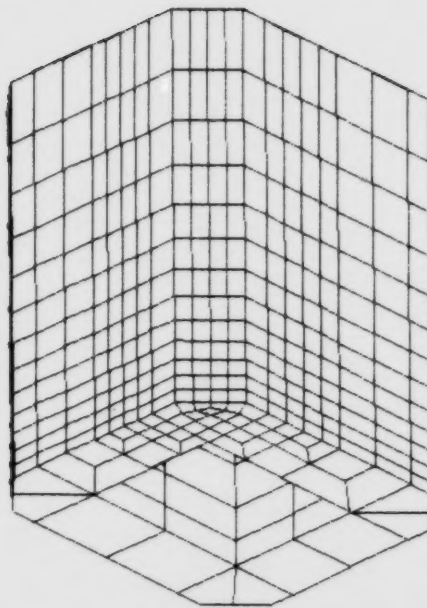
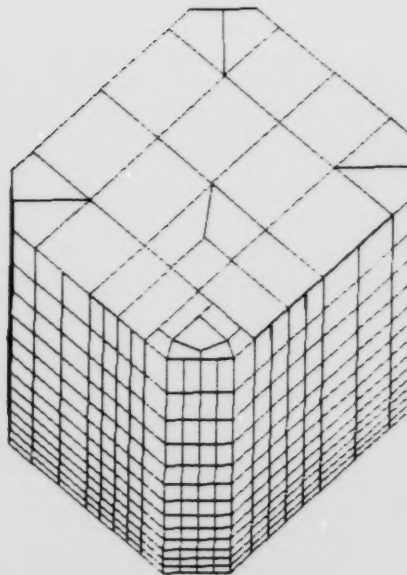


FIGURE 16

CASE 1: SOLID ELEMENTS FOR THE CIC LID CONCRETE



(A) BOTTOM/FRONT VIEW



(B) TOP/REAR VIEW

FIGURE 17

CASE 1: SHELL ELEMENTS FOR THE CONTAINER OUTER LINER

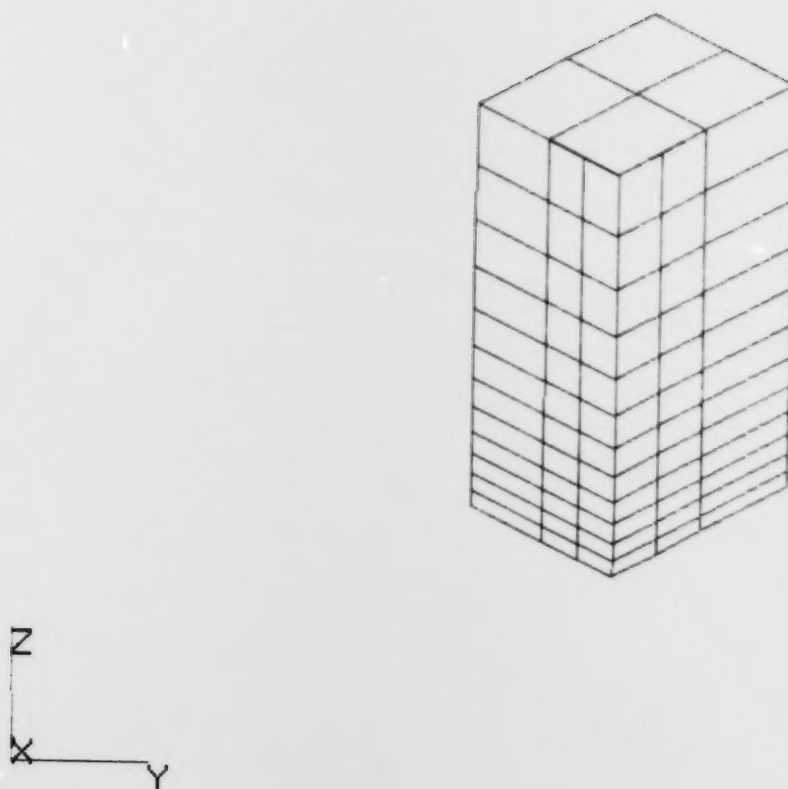


FIGURE 18

CASE 1: SHELL ELEMENTS FOR THE CONTAINER INNER LINER

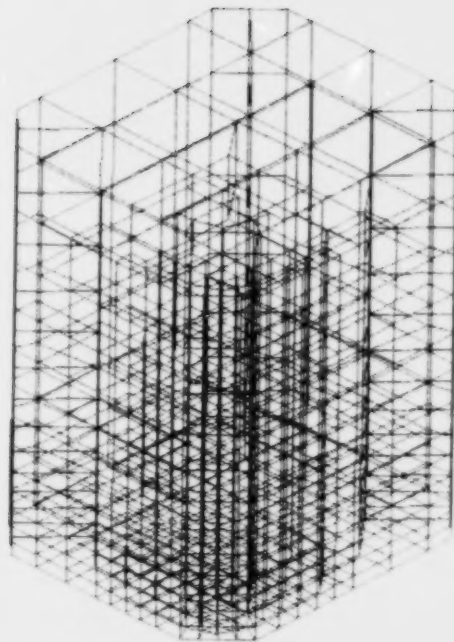


FIGURE 19

CASE 1: SOLID ELEMENTS FOR THE CONTAINER CONCRETE

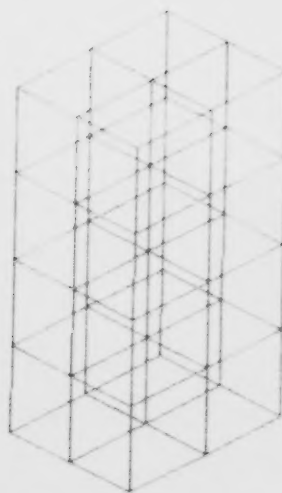


FIGURE 20

CASE 1: SOLID ELEMENTS FOR THE PAYLOAD

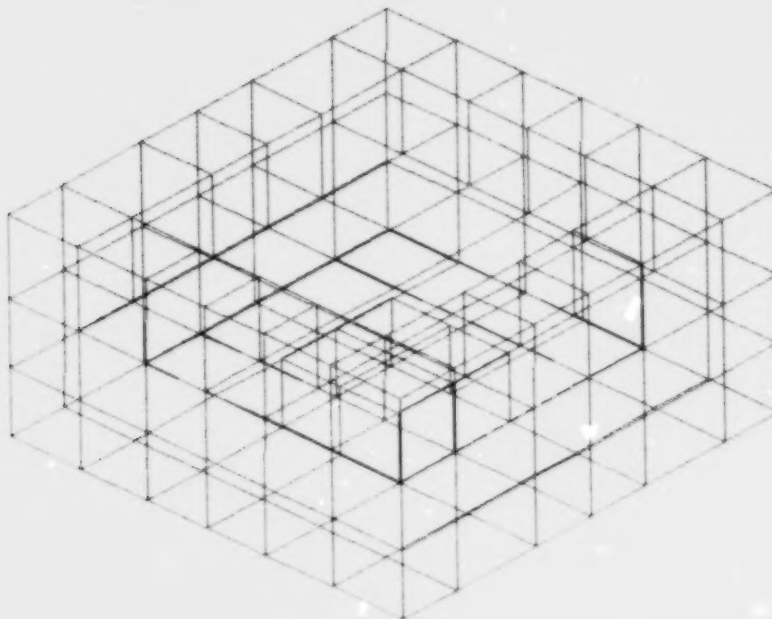


FIGURE 21

CASE 1: SHELL ELEMENTS FOR THE SKINS OF THE IMPACT LIMITER #2

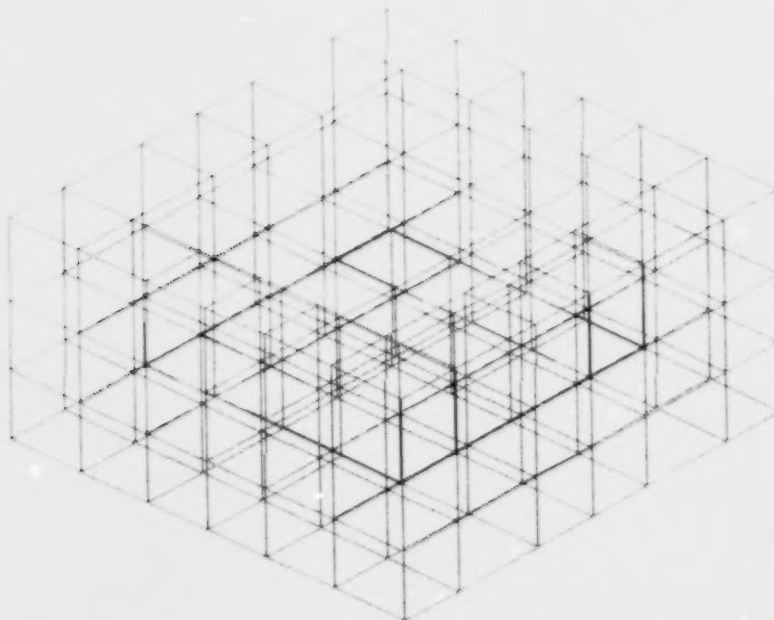


FIGURE 22

**CASE 1: SOLID ELEMENTS FOR THE RIGID POLYURETHANE FOAM
IN THE IMPACT LIMITER #2**

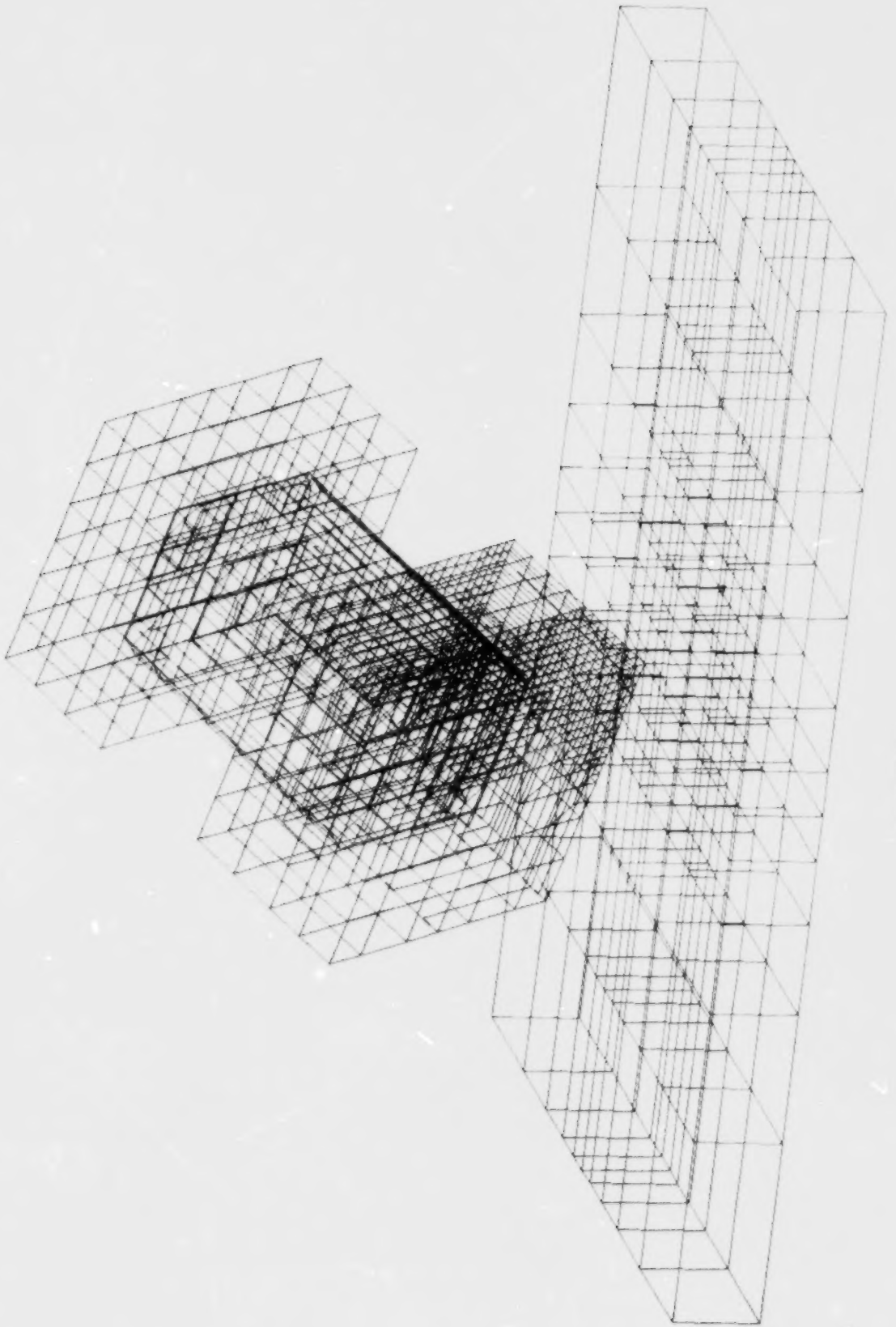


FIGURE 23
CASE 1: SHELL ELEMENTS FOR THE COMPLETE CIC SYSTEM

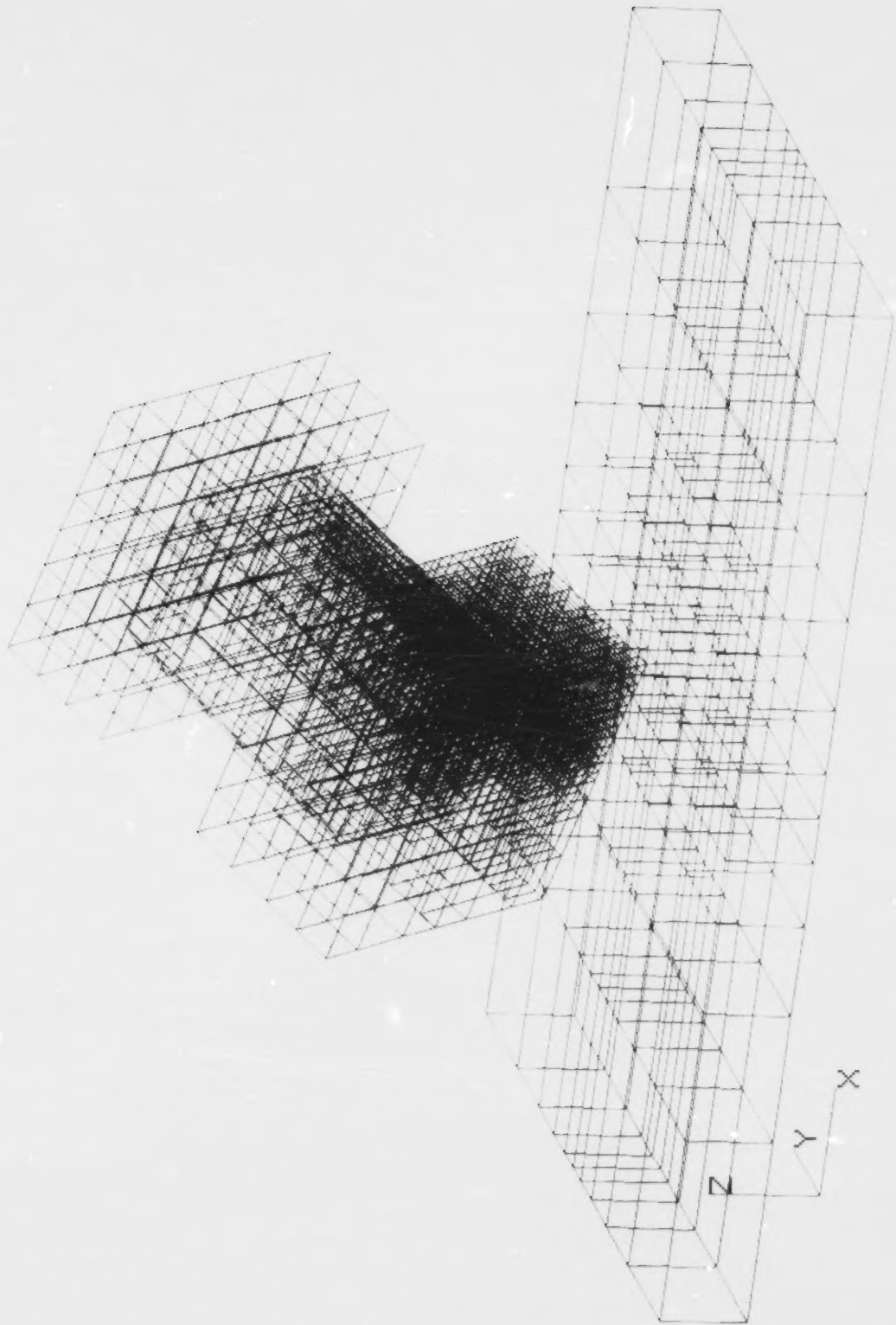


FIGURE 24

CASE 1: SOLID ELEMENTS FOR THE COMPLETE CIC SYSTEM

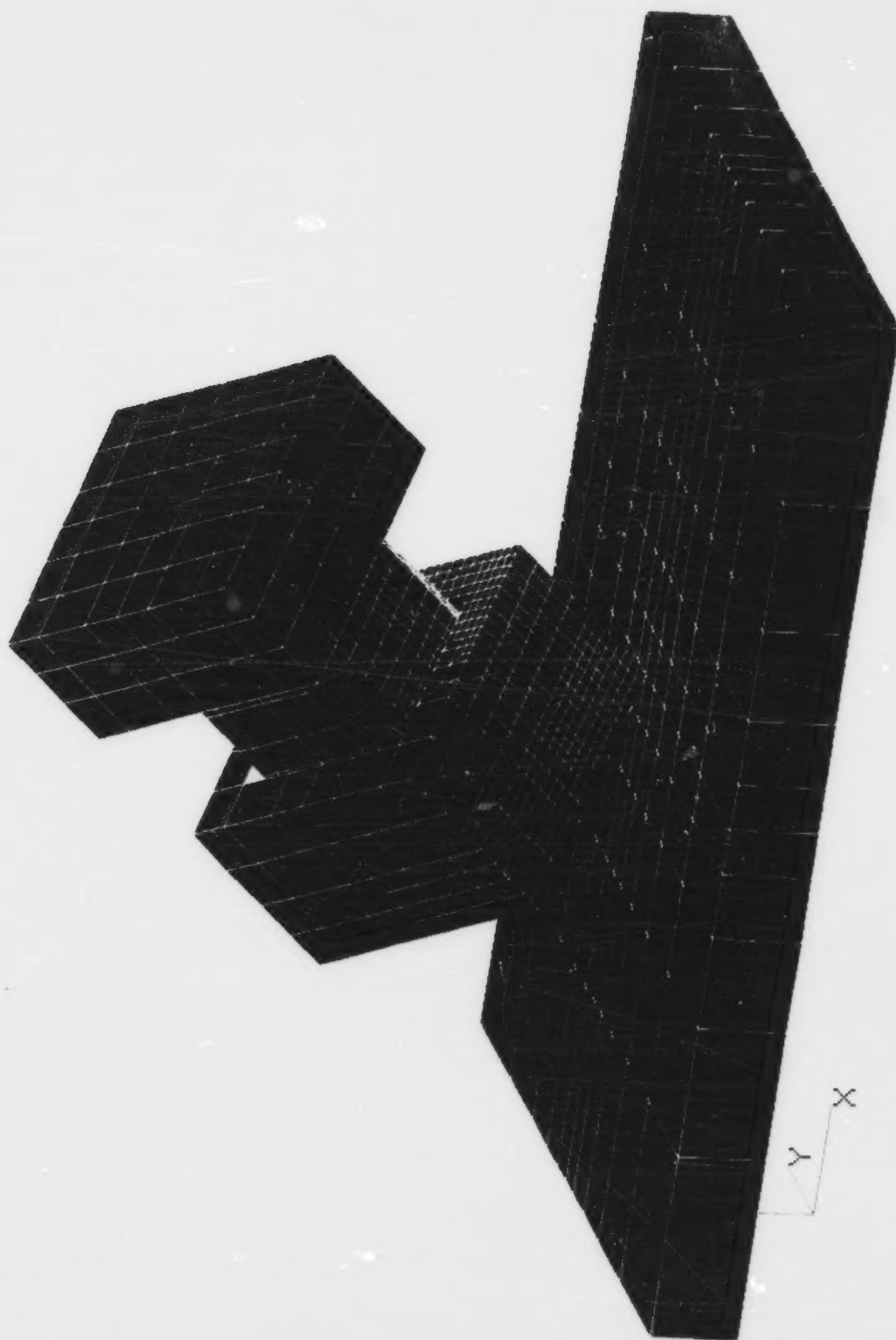


FIGURE 25
SCHEMATIC FINITE ELEMENT MODEL OF THE CIC SYSTEM

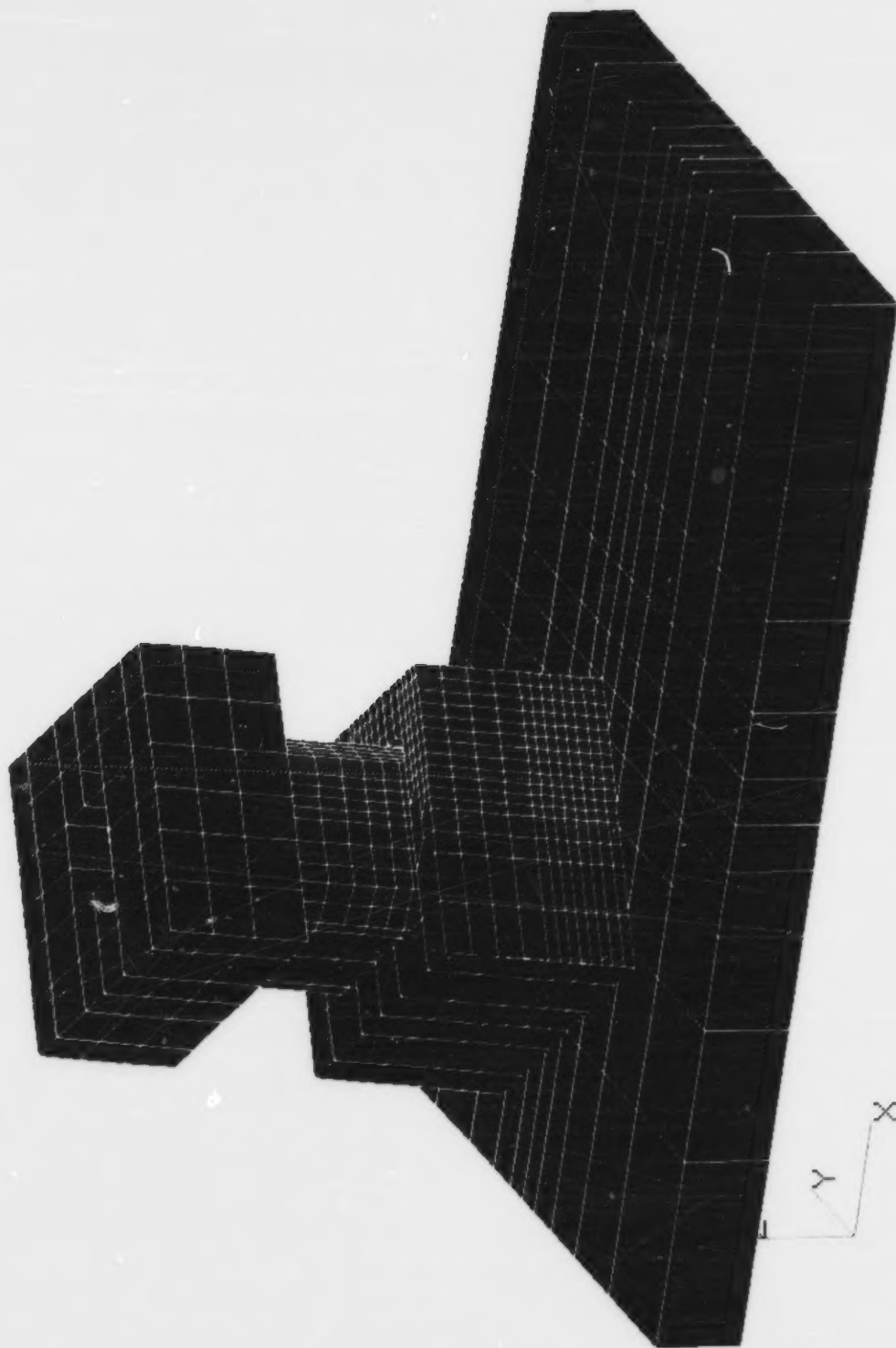


FIGURE 26

CASE 2: SCHEMATIC FINITE ELEMENT MODEL OF THE CIC SYSTEM

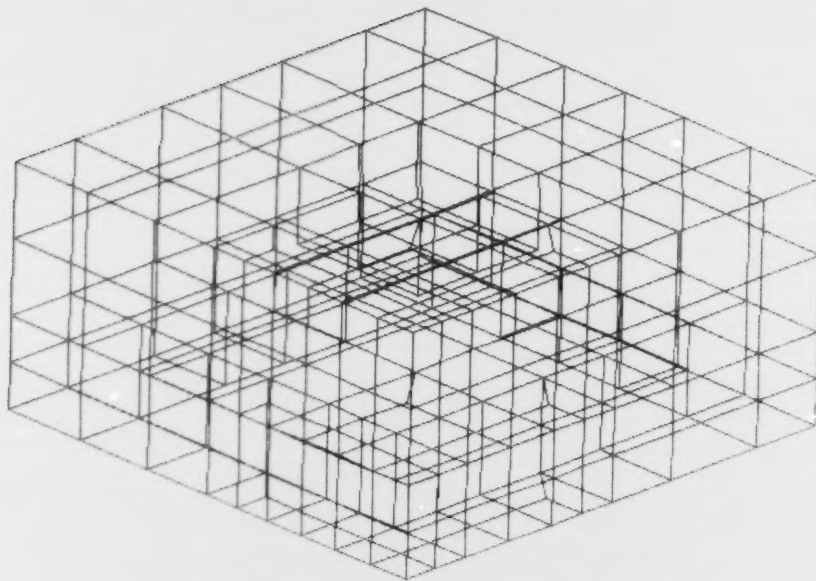


FIGURE 27

CASE 3: SHELL ELEMENTS FOR THE SKINS OF THE IMPACT LIMITER #2

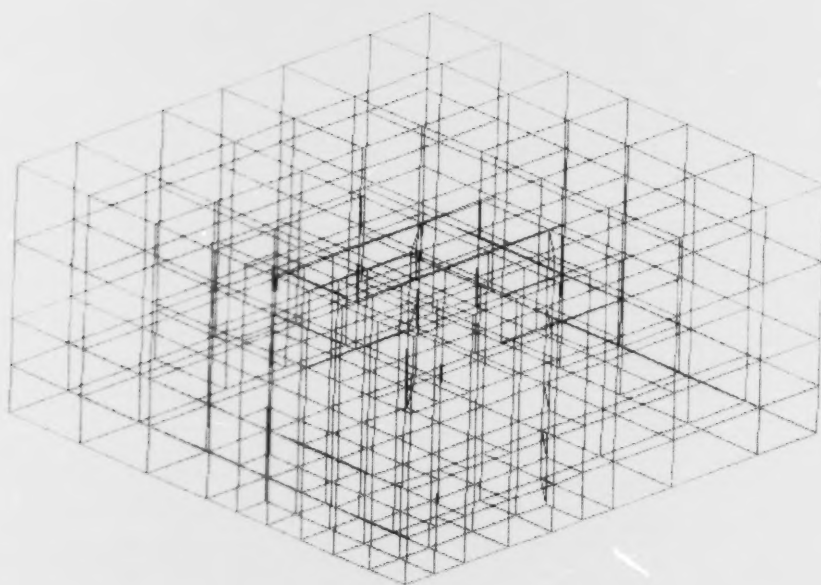


FIGURE 28

CASE 3: SOLID ELEMENTS FOR THE RIGID FOAM IN THE IMPACT LIMITER #2

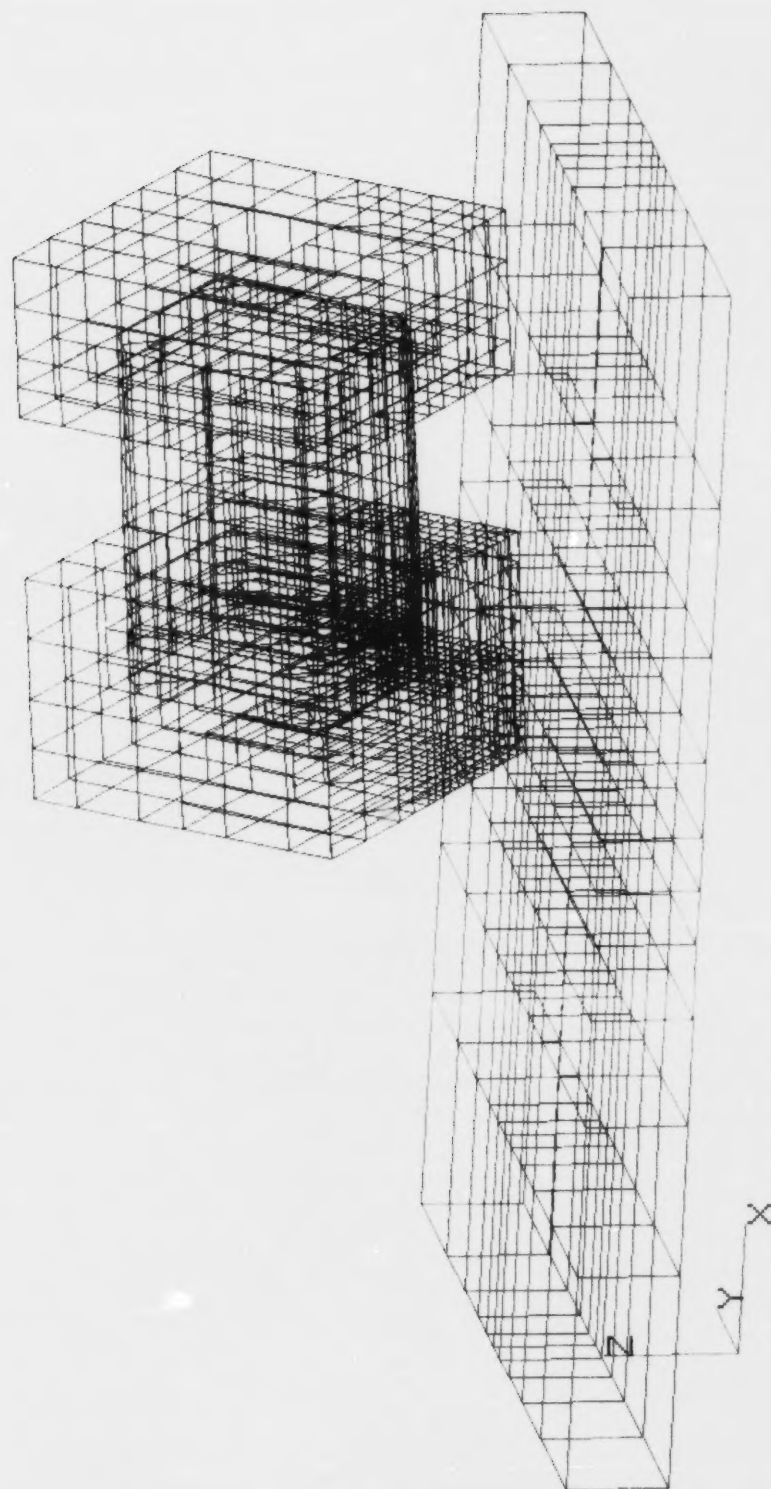


FIGURE 29

CASE 3: SHELL ELEMENTS FOR THE COMPLETE CIC SYSTEM

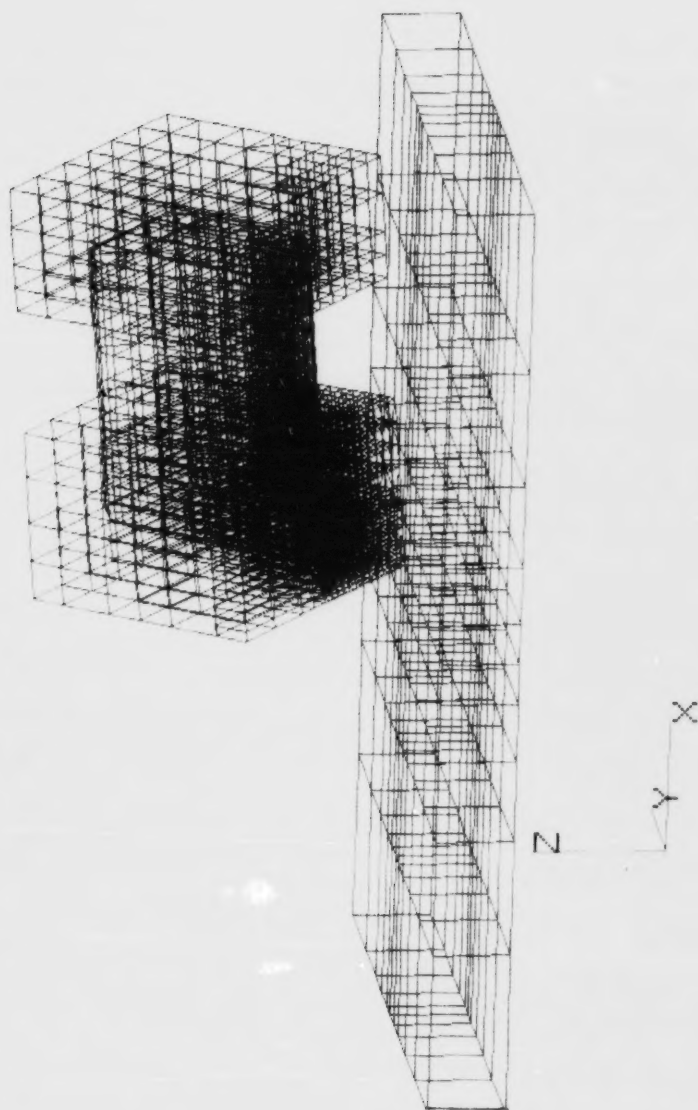


FIGURE 30

CASE 3: SOLID ELEMENTS FOR THE COMPLETE CIC SYSTEM

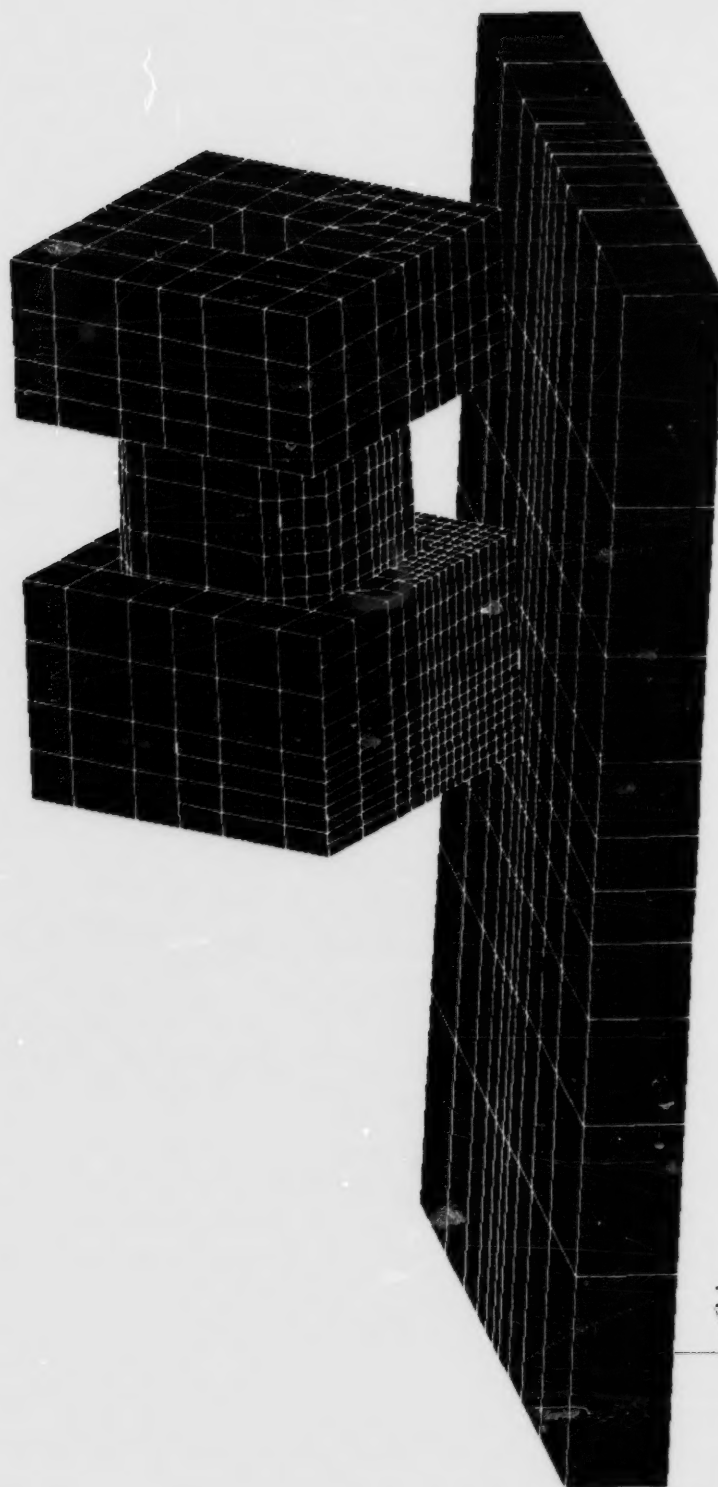


FIGURE 31

CASE 3: SCHEMATIC FINITE ELEMENT MODEL OF THE CIC SYSTEM

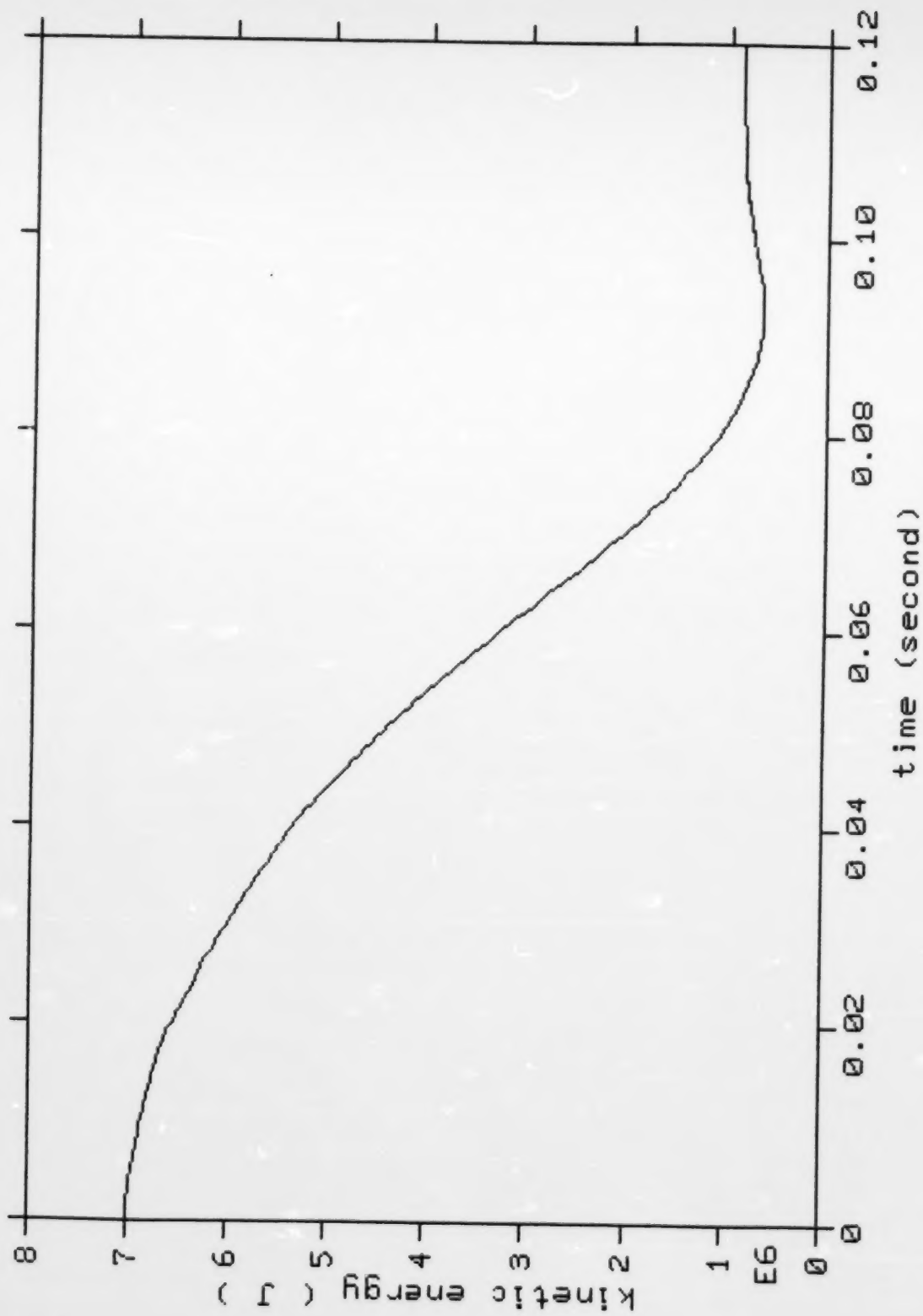


FIGURE 32

CASE 1: KINETIC ENERGY TIME HISTORY OF THE CIC

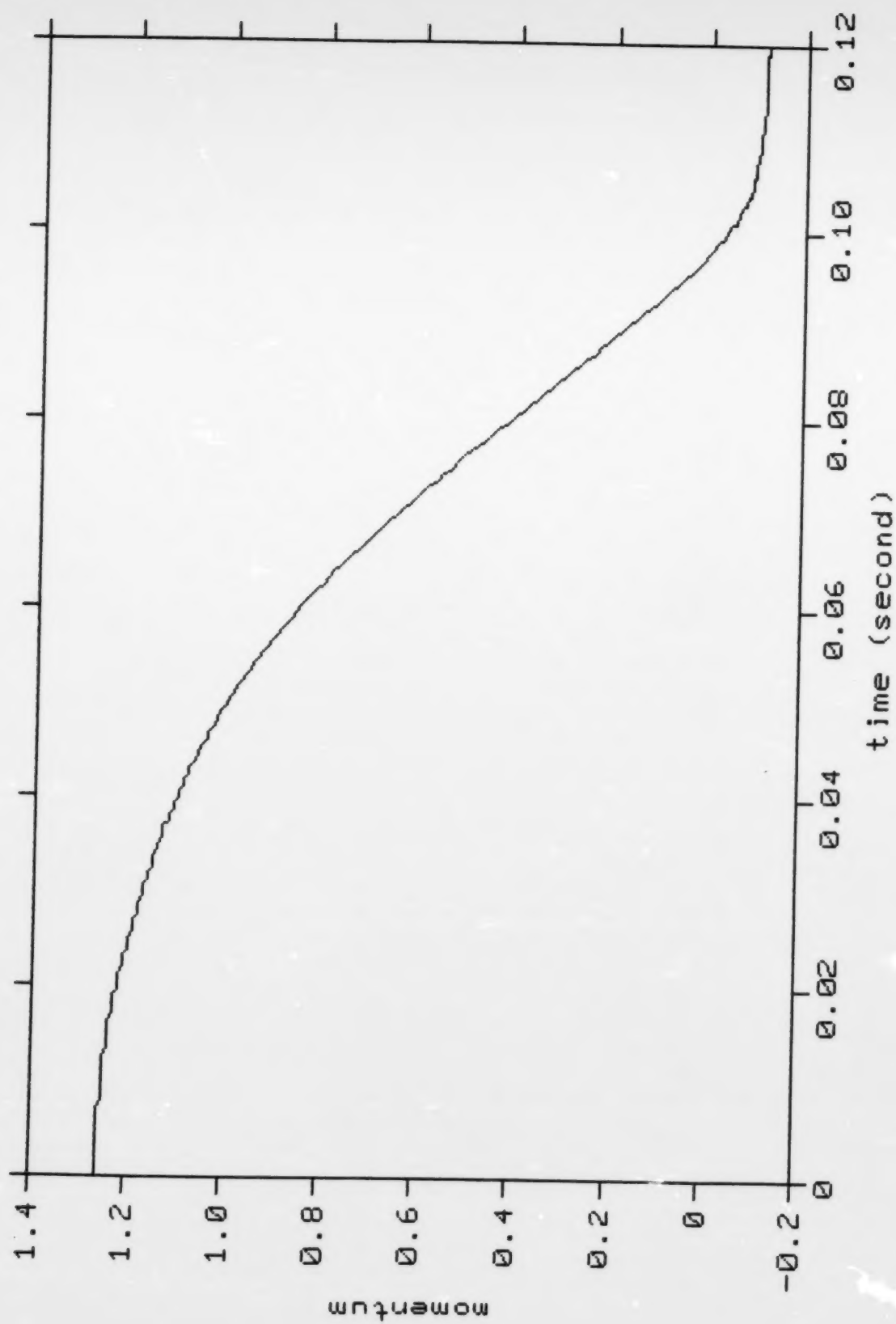


FIGURE 33

CASE 1: NORMALIZED MOMENTUM TIME HISTORY OF THE CIC

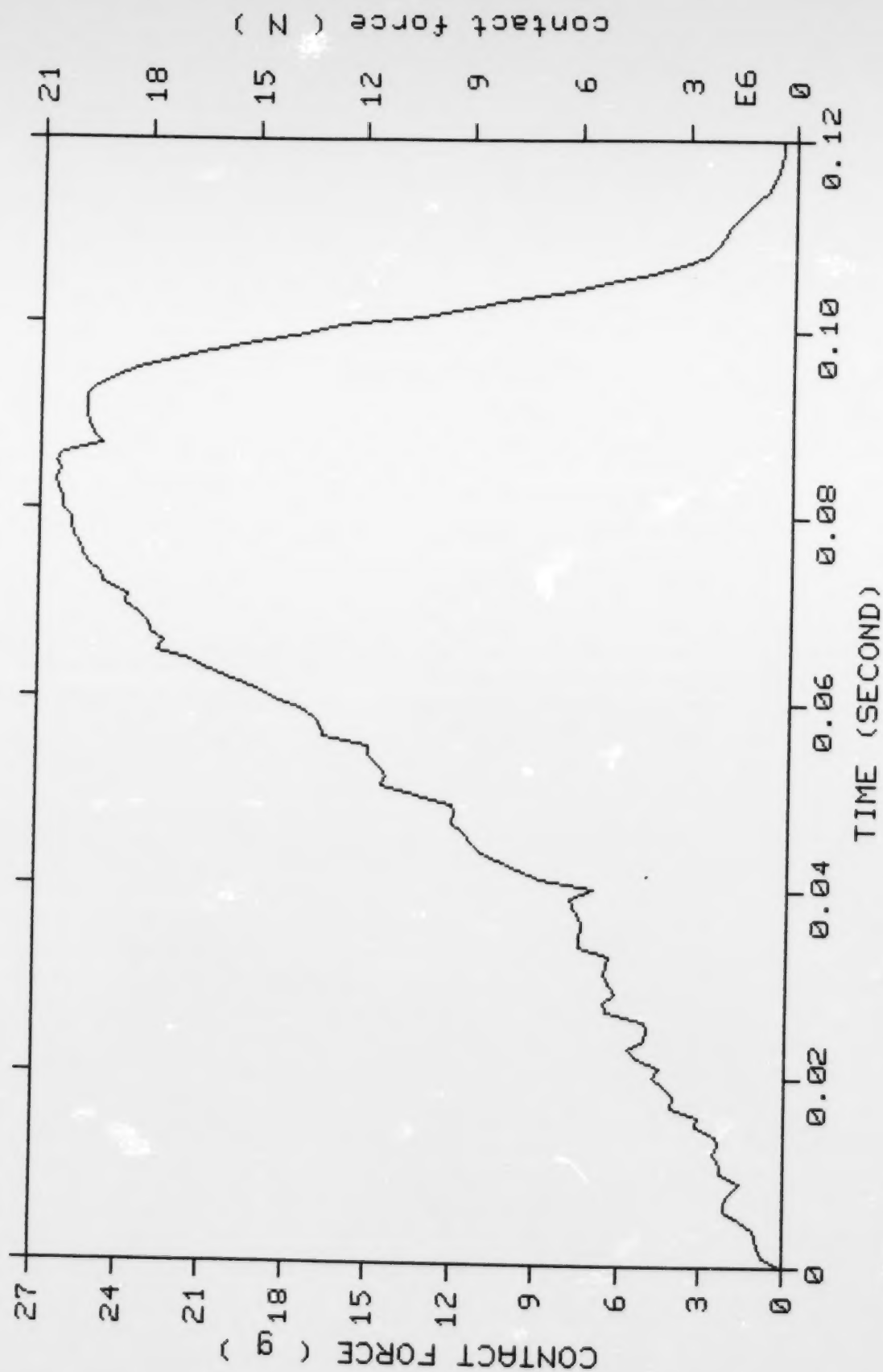


FIGURE 34

CASE 1: CONTACT FORCE TIME HISTORY OF THE CIC

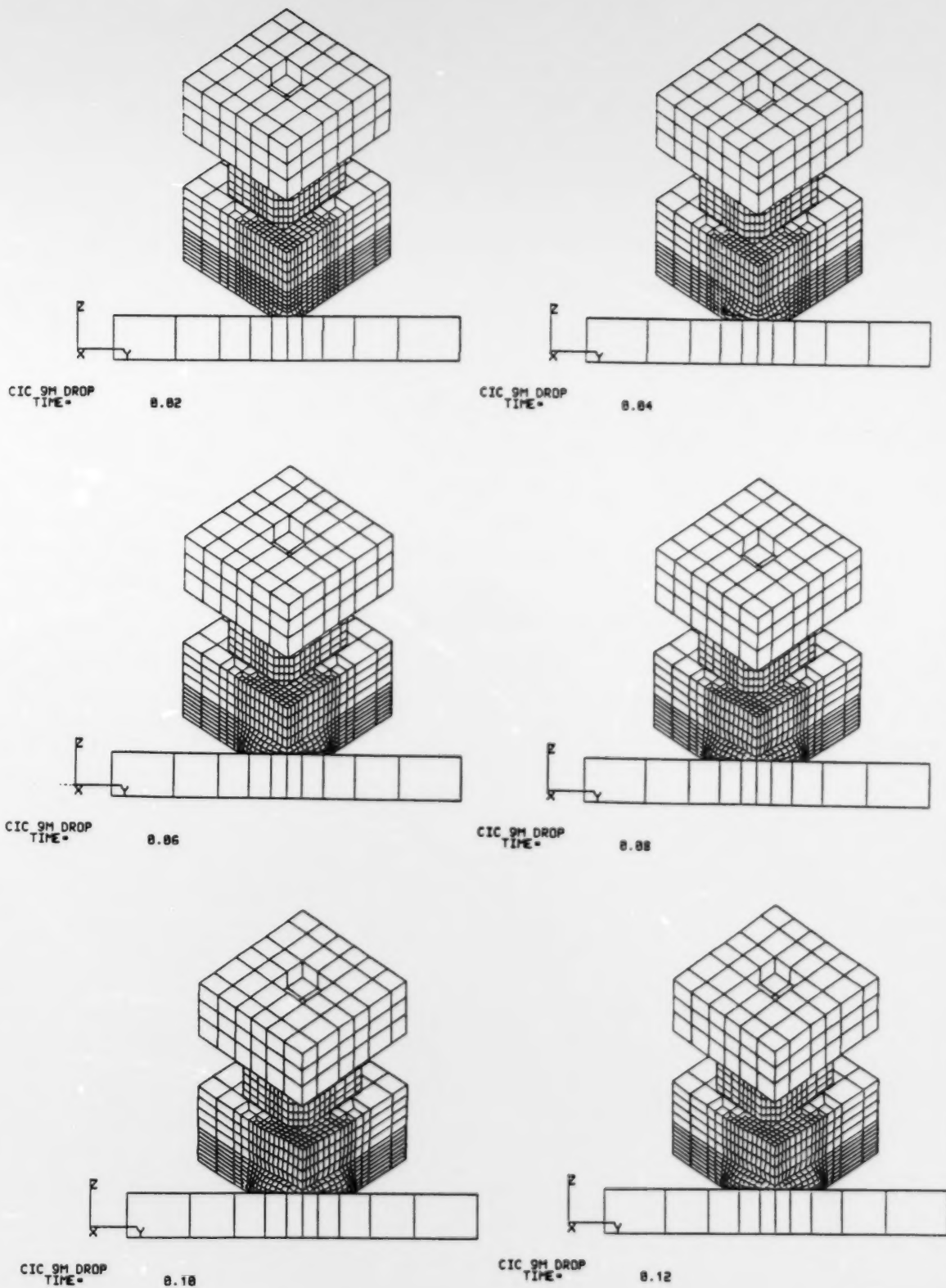
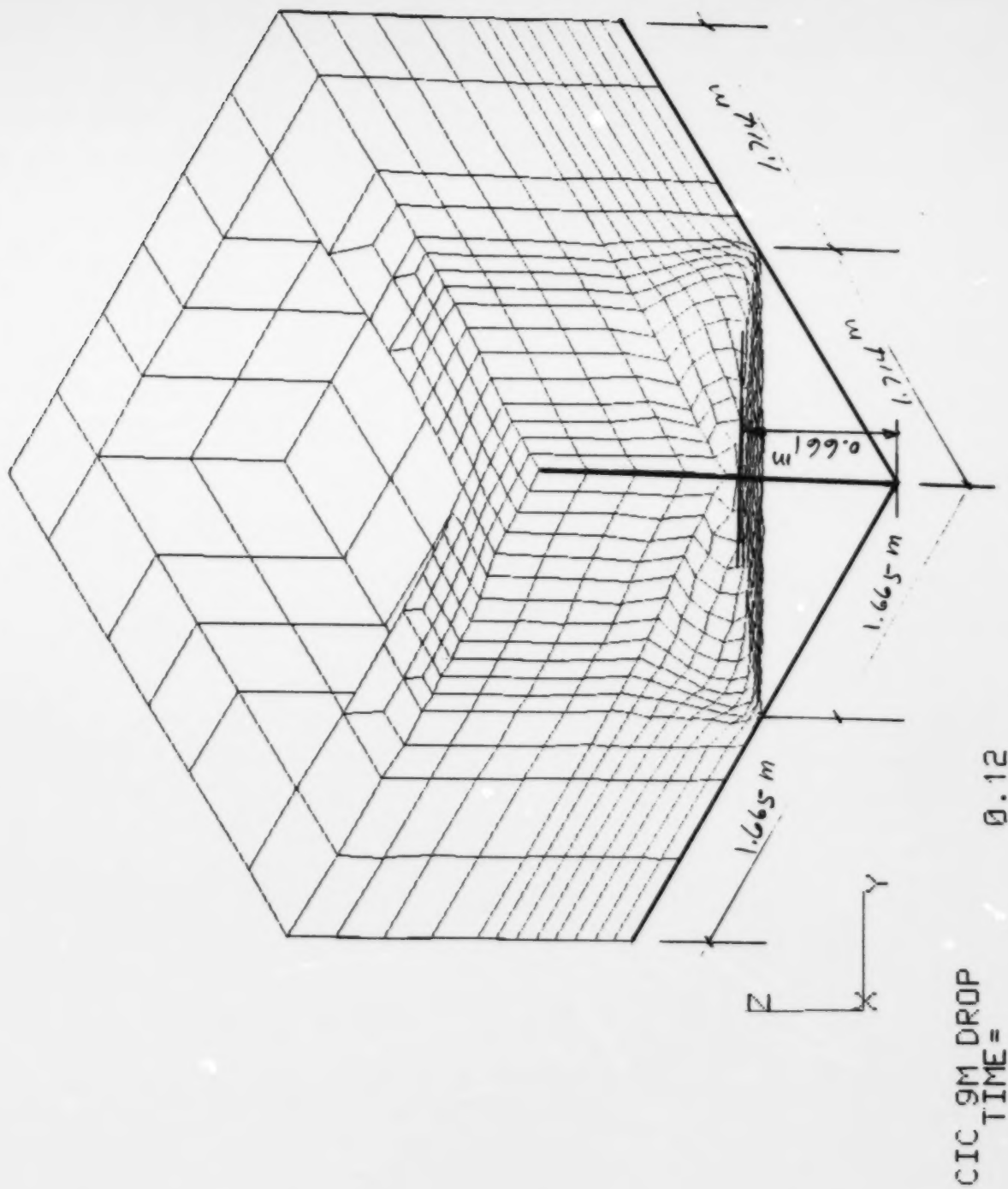


FIGURE 35

CASE 1: SEQUENTIAL DEFORMATION OF THE CIC



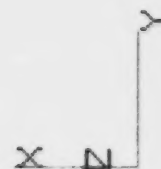
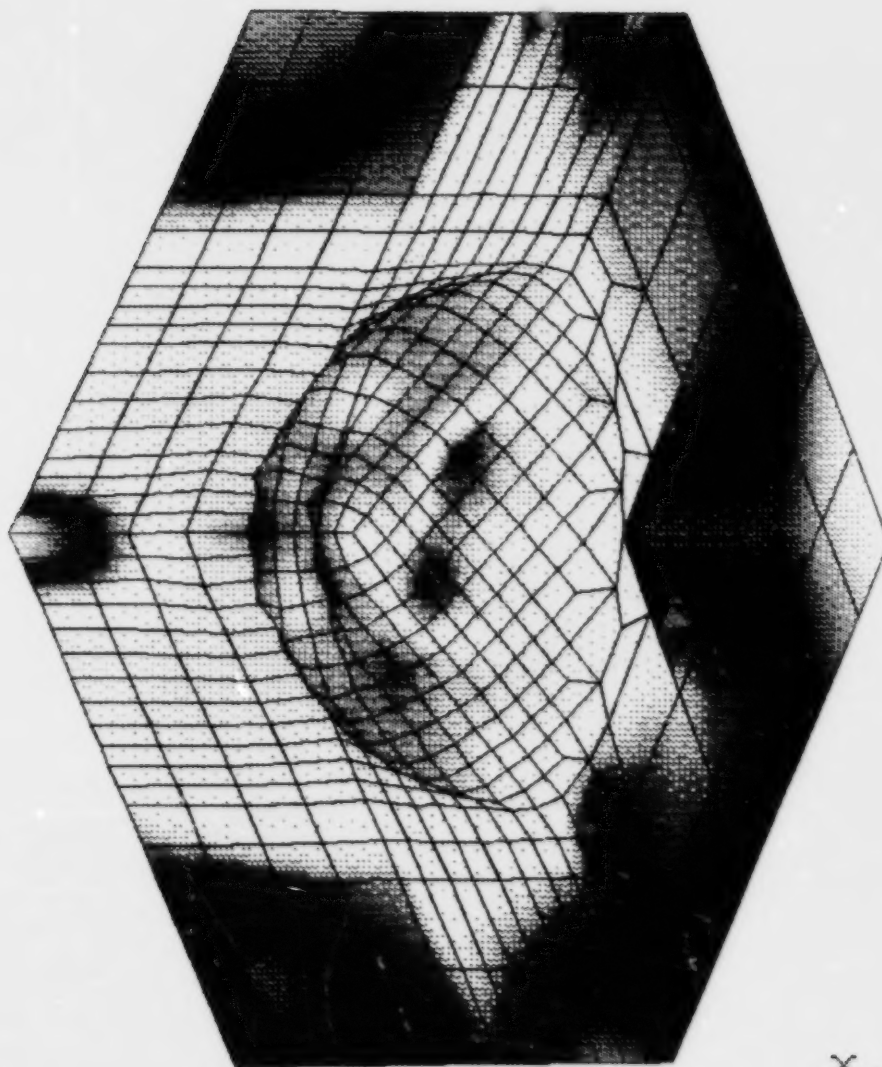
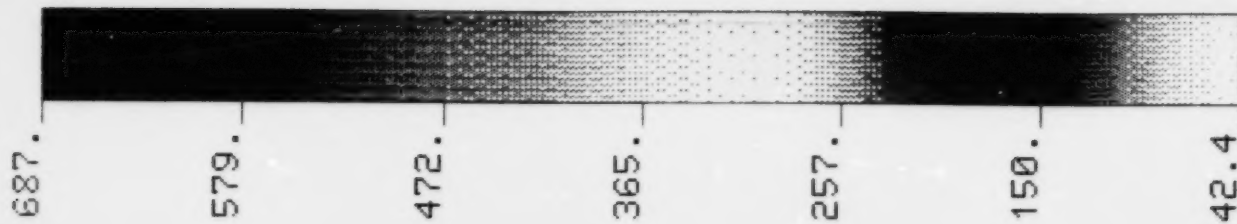


FIGURE 37

CASE 1: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #1 AT 0.08 SECOND (BOTTOM/FRONT VIEW)

CIC 9M DROP
TIME =

0.08

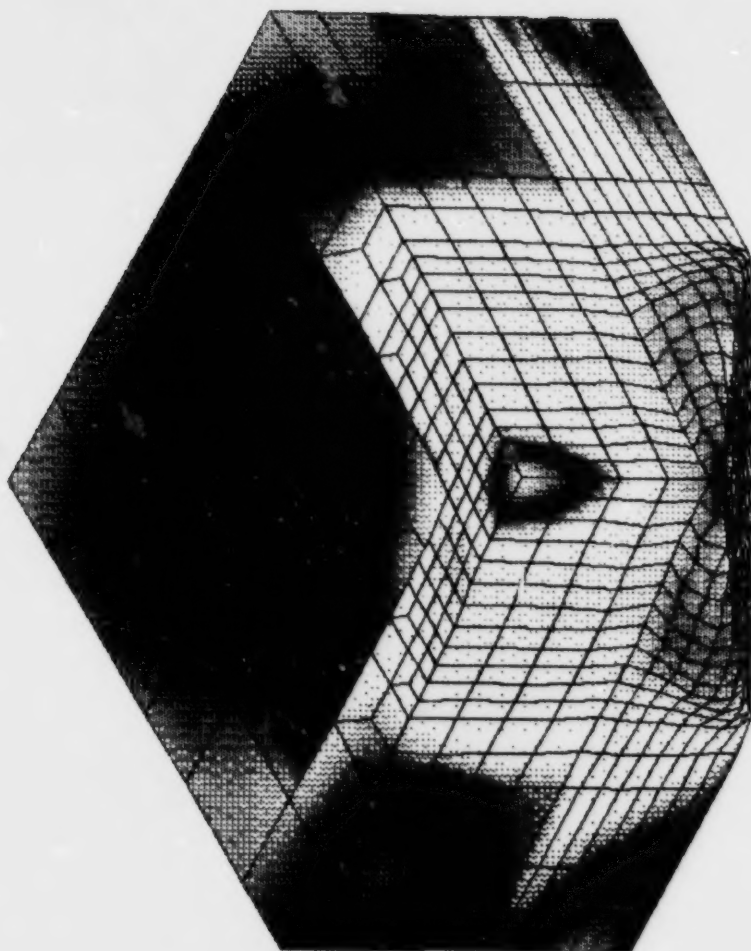
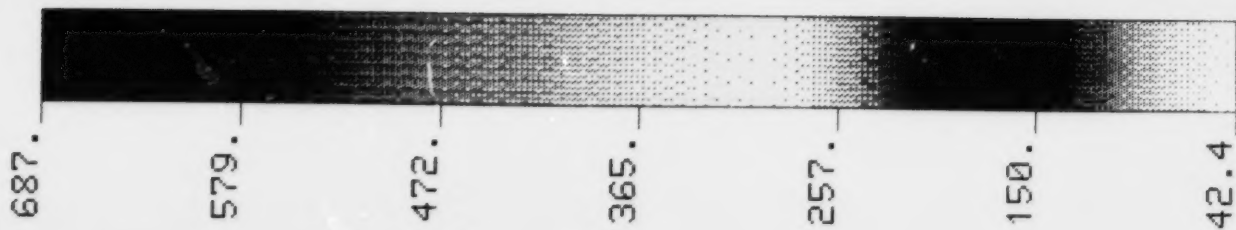


FIGURE 38

CASE 1: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #1 AT 0.08 SECOND (FRONT VIEW) (MPa)

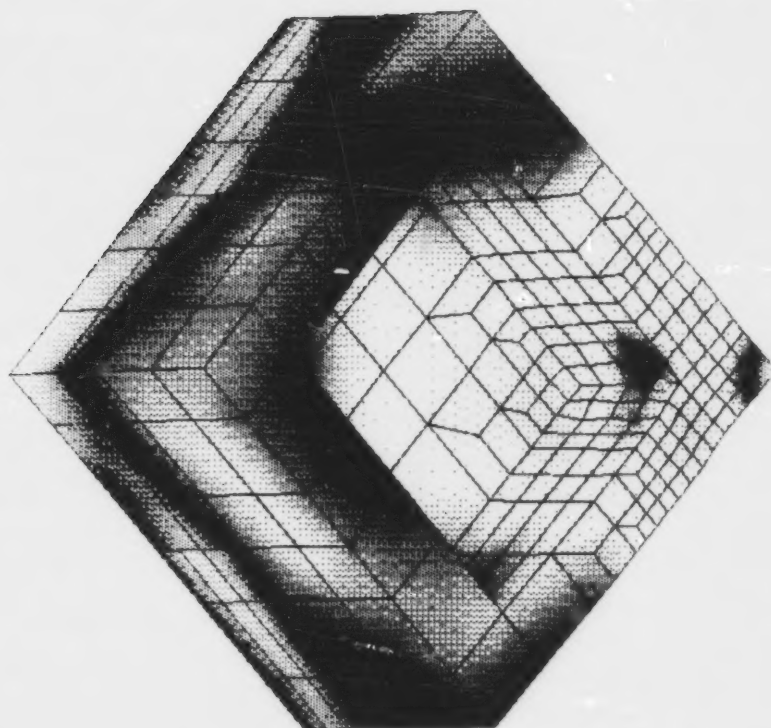
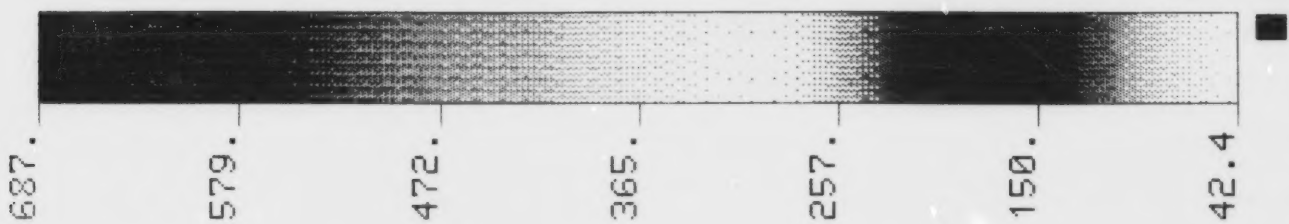


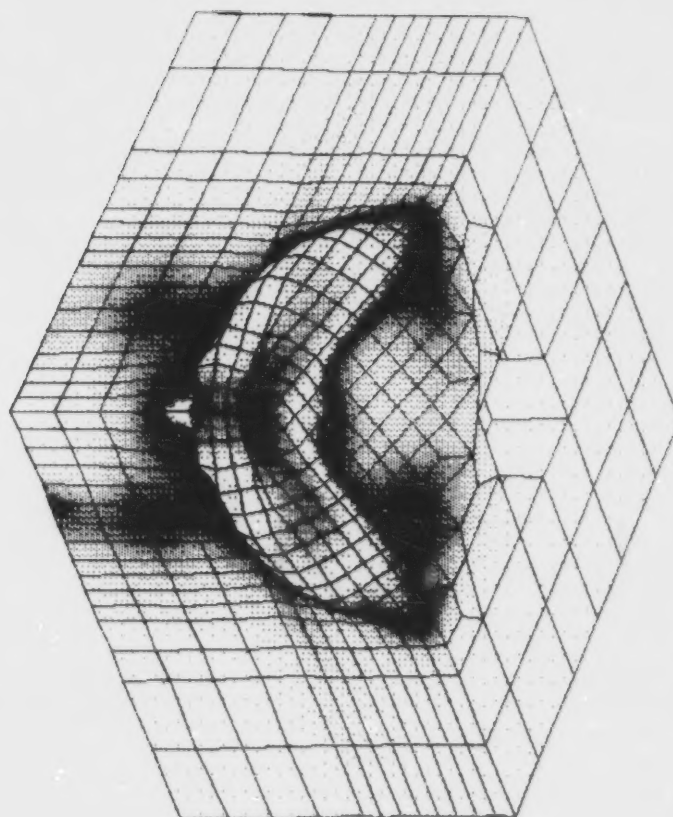
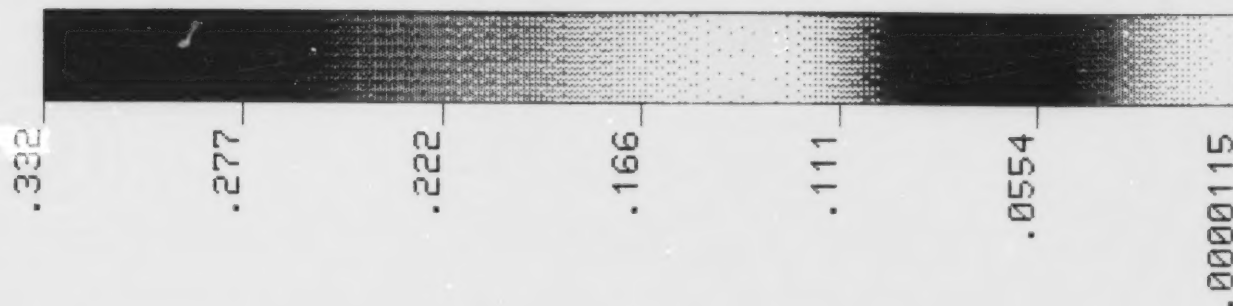
FIGURE 39

CASE 1: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #1 AT 0.08 SECOND (TOP/REAR VIEW) (MPa)

Z Y

CIC 9M DROP
TIME = X

0.08



X Y Z

FIGURE 40
CASE 1: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
STAINLESS STEEL SKIN OF THE IMPACT LIMITER #1 AT 0.10 SECOND
(BOTTOM/FRONT VIEW) (mm/mm)

CIC_9M_DROP
TIME= 0.10

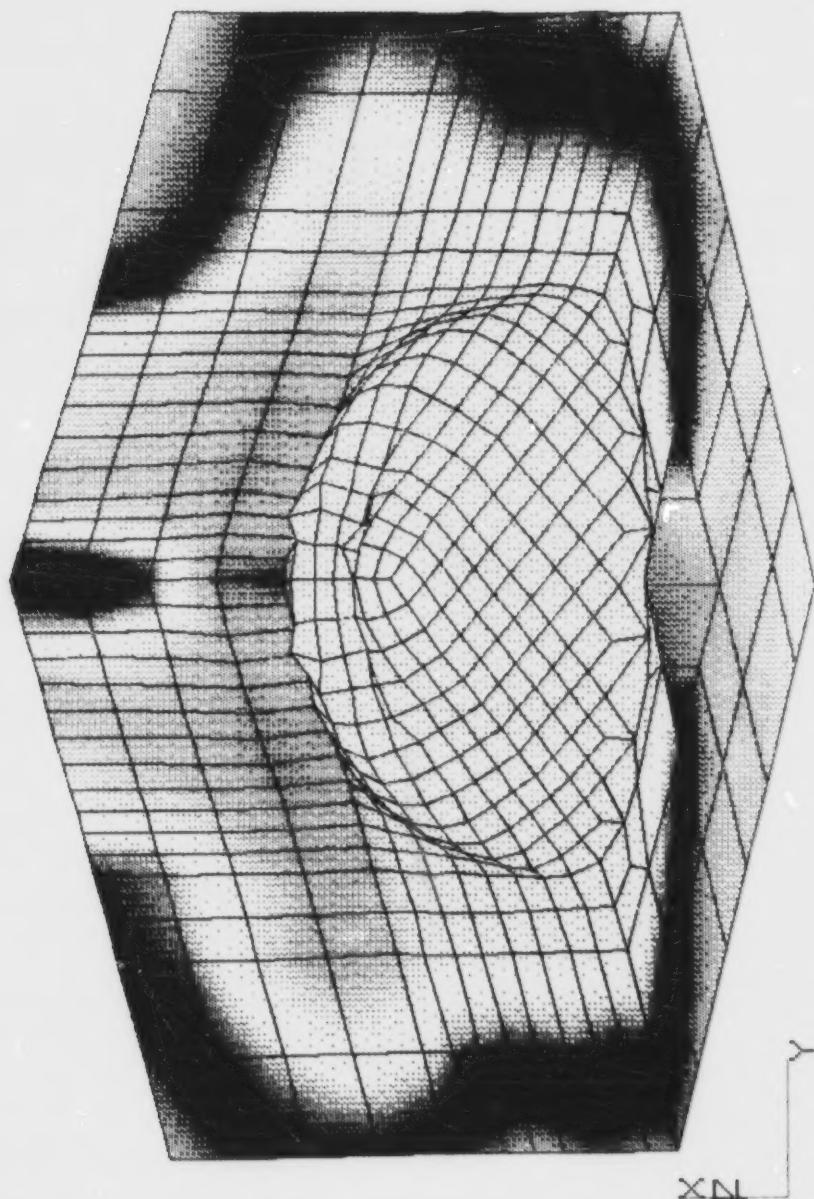
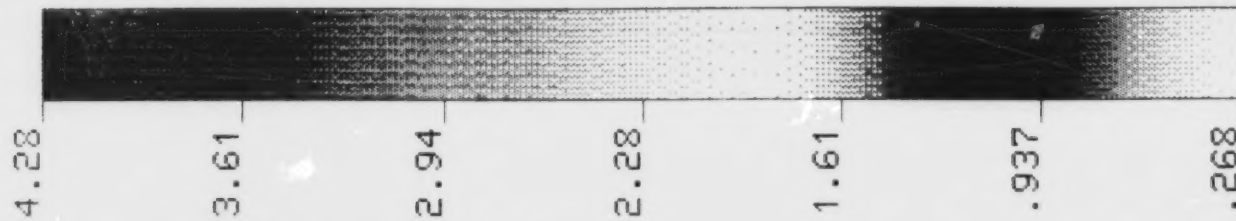


FIGURE 41

CASE 1: EFFECTIVE STRESS IN THE RIGID FOAM OF THE IMPACT
LIMITER #1 AT 0.08 SECOND (FRONT VIEW) (MPa)

CIC_9M_DROP
TIME=

0.08

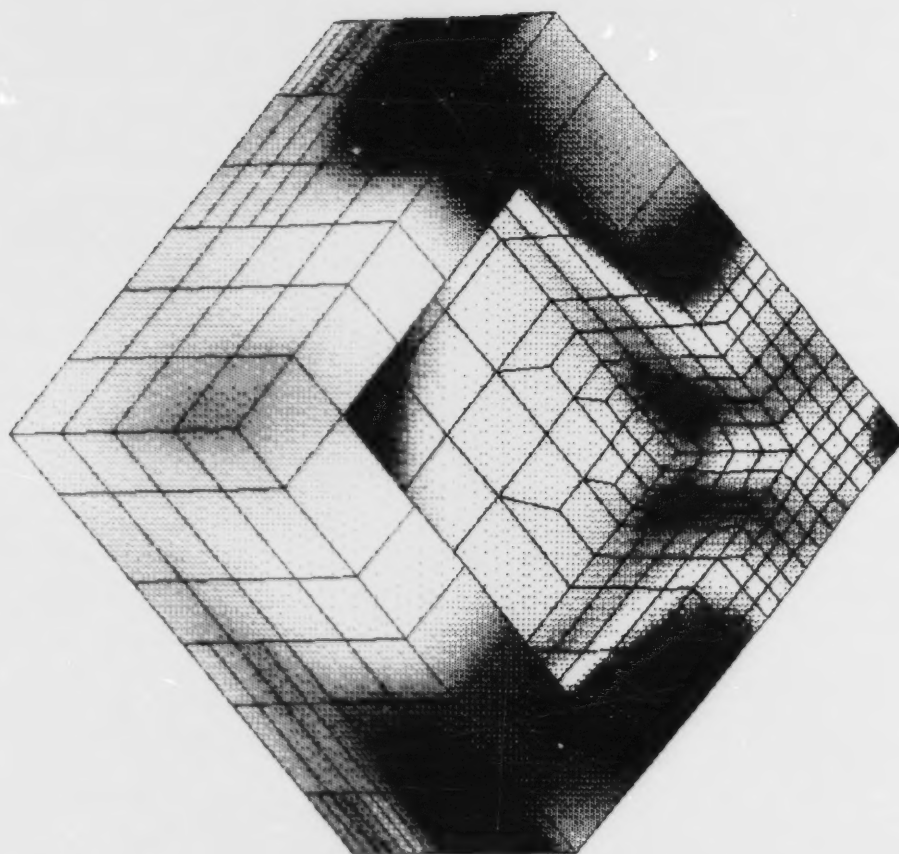
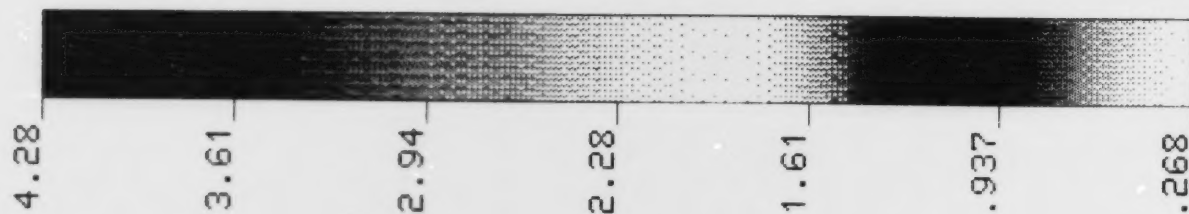


FIGURE 42

CASE 1: EFFECTIVE STRESS IN THE RIGID FOAM OF THE IMPACT
LIMITER #1 AT 0.08 SECOND (TOP/REAR VIEW) (MPa)

Z
Y

CIC 9M DROP
TIME = X

0.08

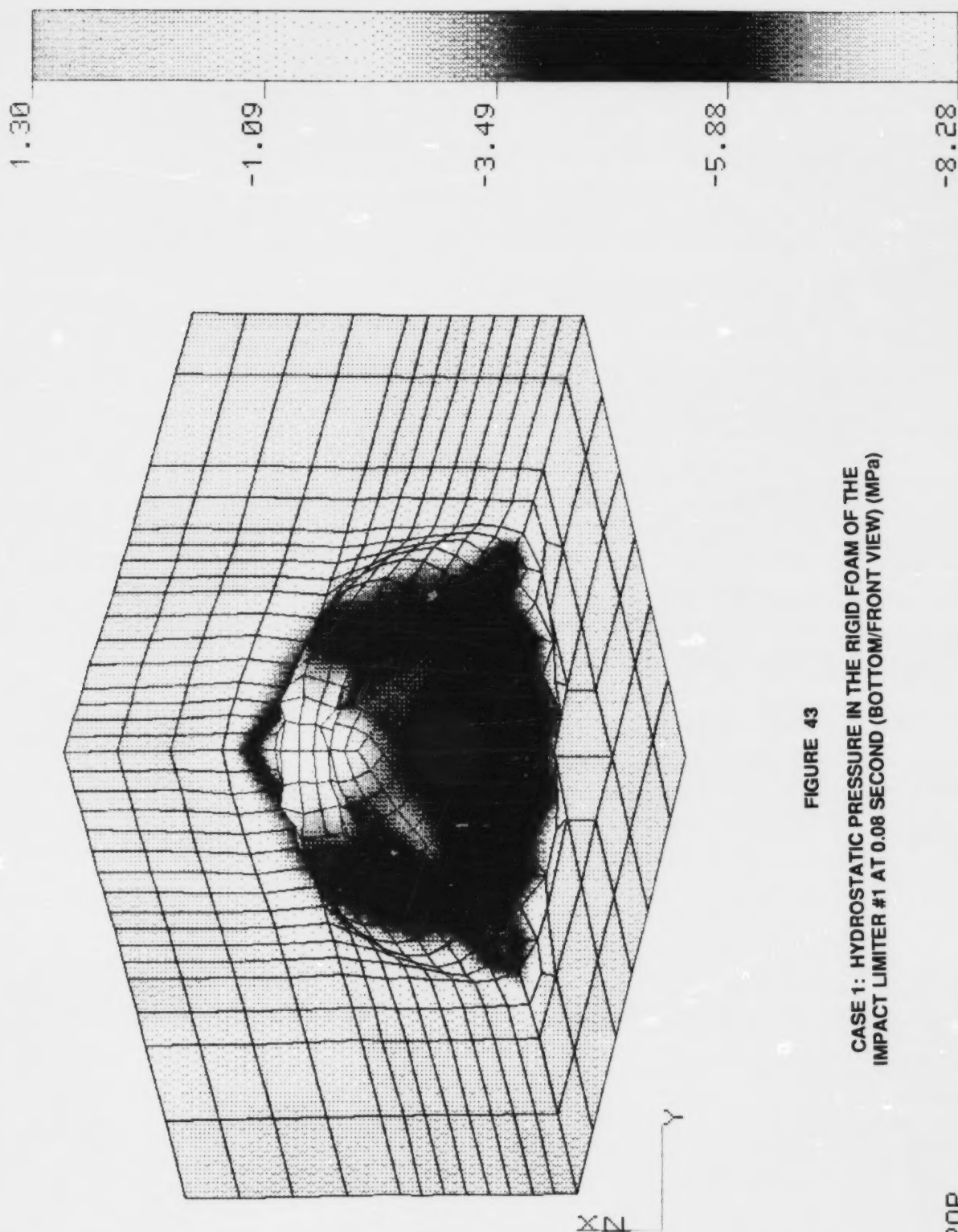


FIGURE 43

CASE 1: HYDROSTATIC PRESSURE IN THE RIGID FOAM OF THE
IMPACT LIMITER #1 AT 0.08 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.08

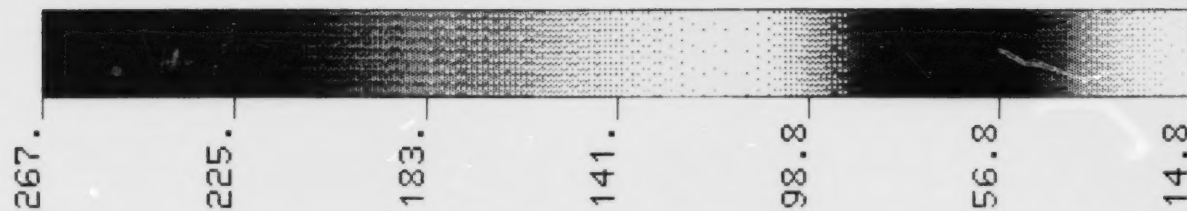
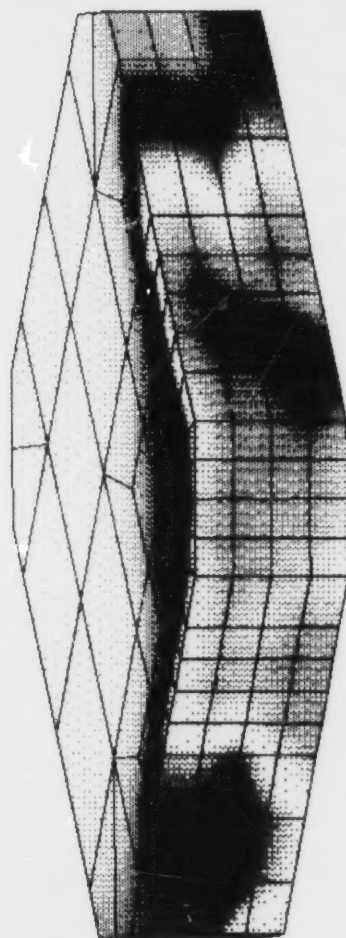
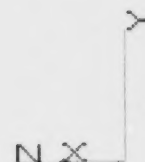


FIGURE 4 4

CASE 1: VON MISES STRESS IN THE LID PLATES AT 0.08 SECOND
(TOP/FRONT VIEW) (MPa)



CIC 9M DROP
TIME =

0.08

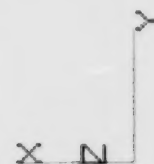
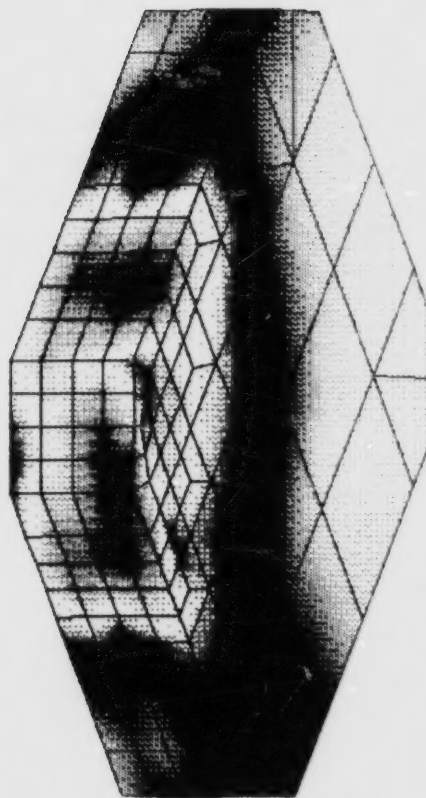
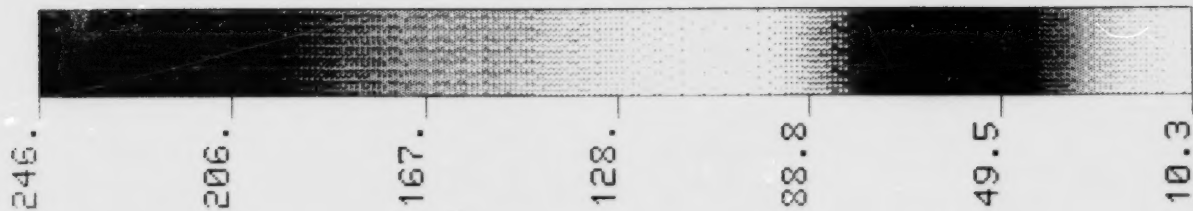


FIGURE 45

CASE 1: VON MISES STRESS IN THE LID PLATES AT 0.10 SECOND
(BOTTOM/FRONT VIEW) (MPa)

CIC_9M_DROP
TIME =

0.10

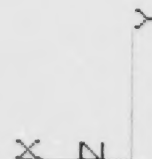
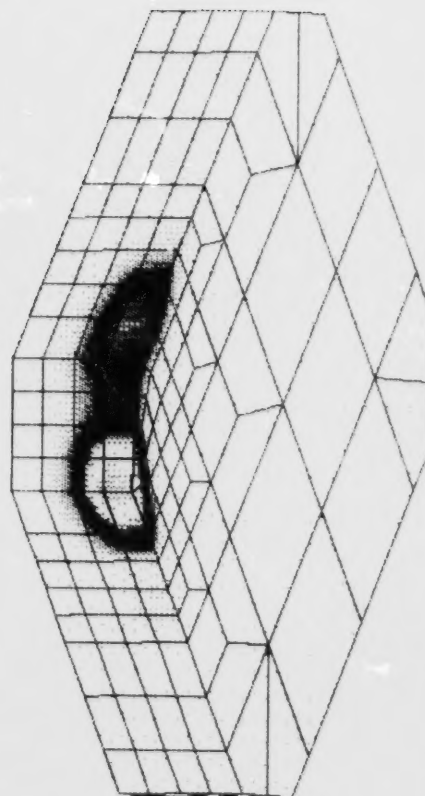
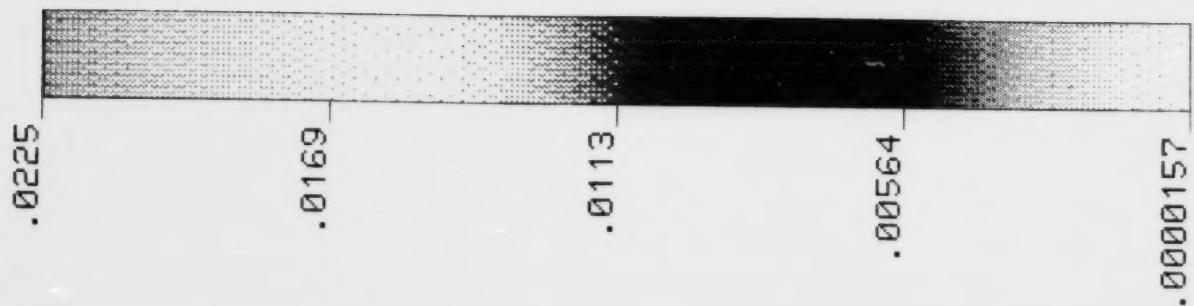


FIGURE 46

CASE 1: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE LID PLATES
AT 0.10 SECOND (BOTTOM/Front VIEW) (mm/mm)

CIC 9M DROP
TIME =

0.10

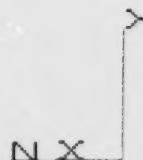
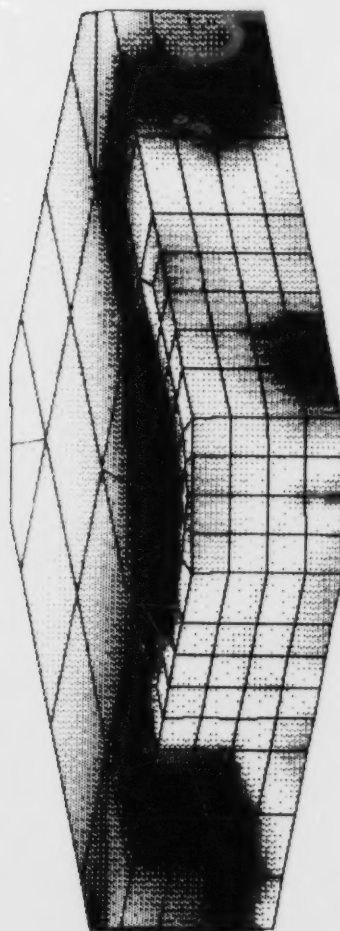
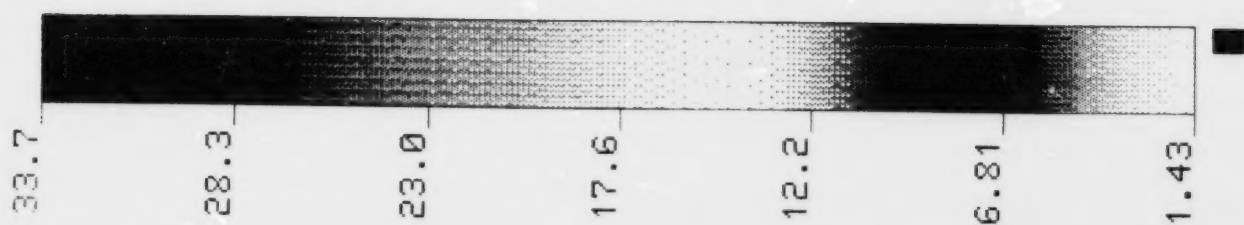


FIGURE 47

CASE 1: EFFECTIVE STRESS IN THE CONCRETE OF THE LID AT
0.08 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME = 0.08

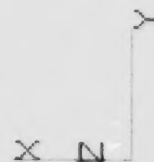
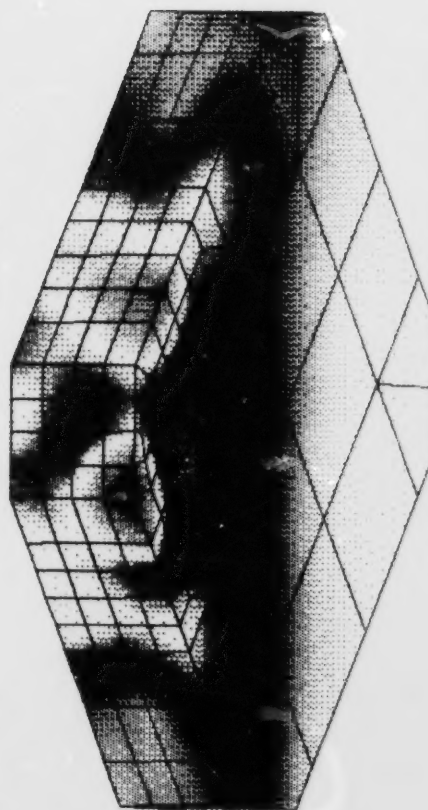
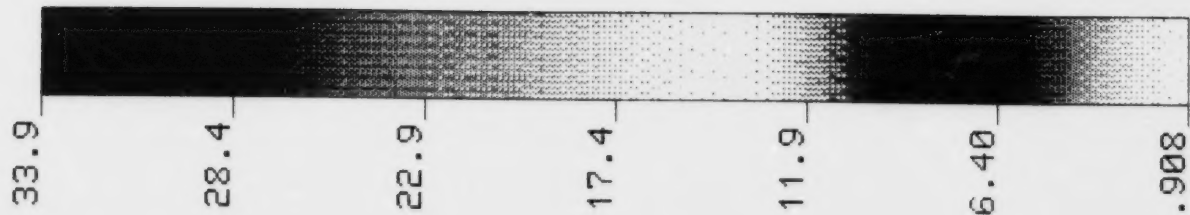
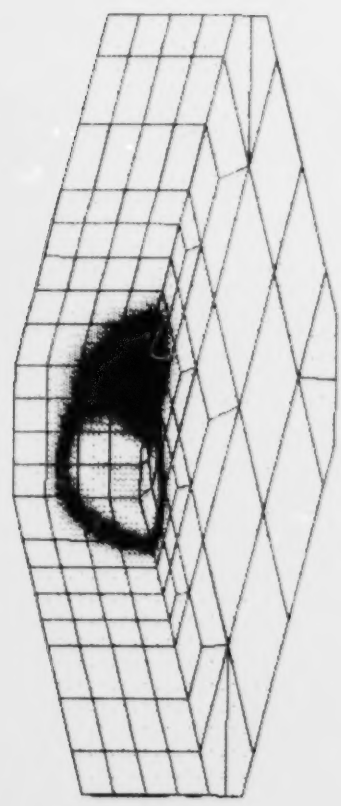


FIGURE 48
CASE 1: EFFECTIVE STRESS IN THE CONCRETE OF THE LID AT
0.10 SECOND (BOTTOM/FRONT VIEW (mm/mm))

CIC 9M DROP
TIME = 0.10



X Z Y

FIGURE 49
CASE 1: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
CONCRETE OF THE LID AT 0.10 SECOND (BOTTOM/FRONT VIEW (mm/mm))

CIC 9M DROP
TIME = 0.10

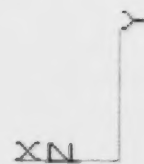
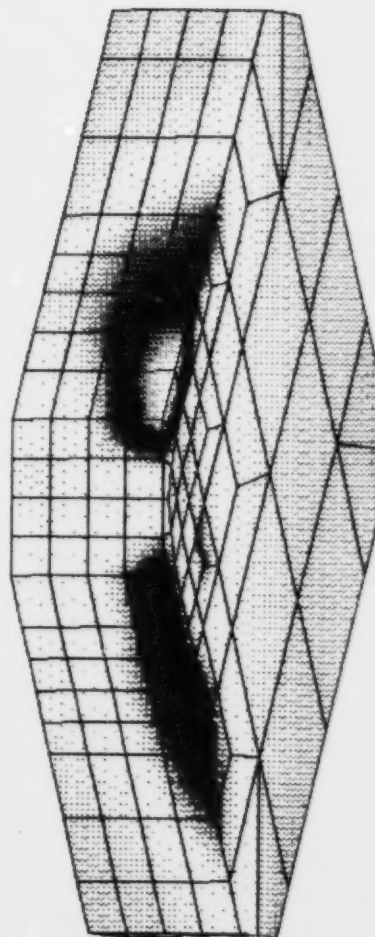
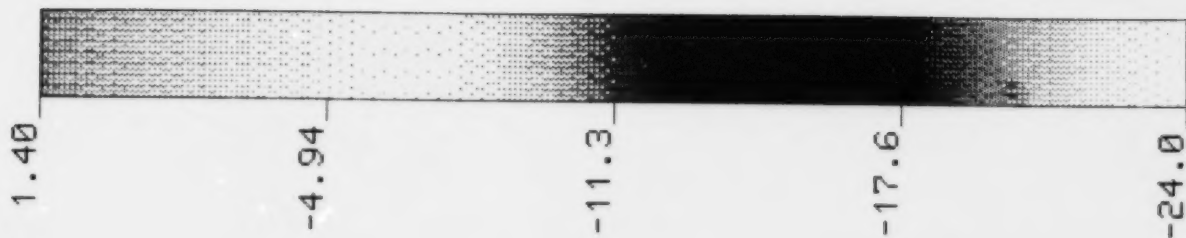
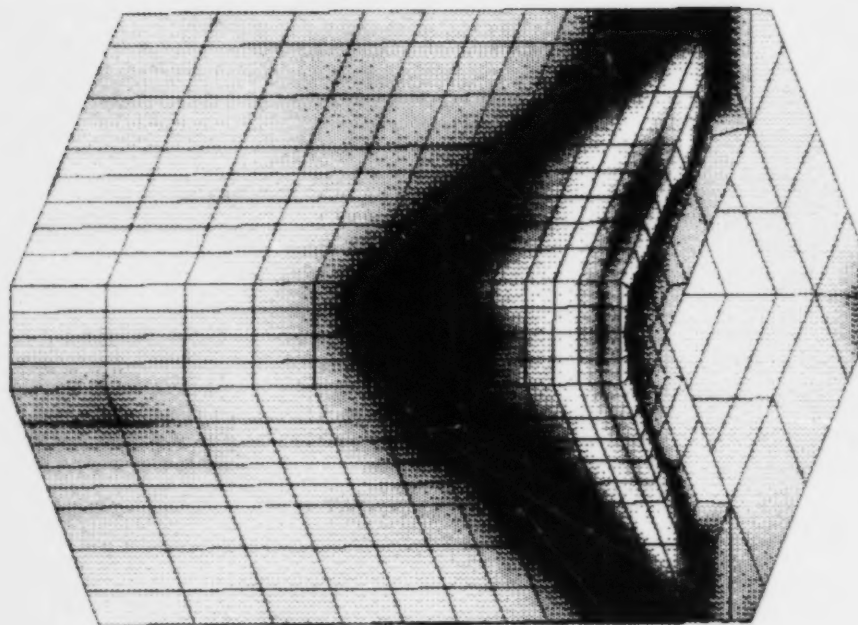
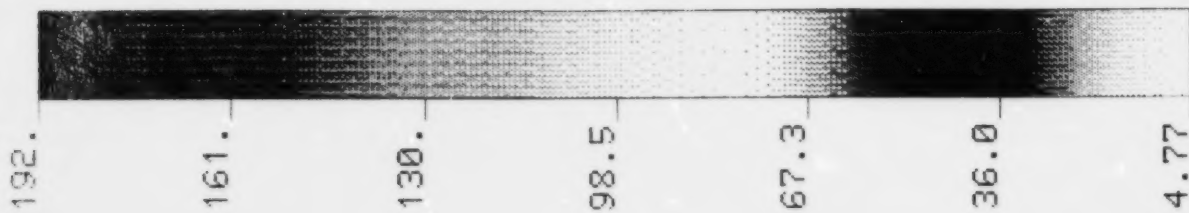


FIGURE 50

CASE 1: HYDROSTATIC PRESSURE IN THE CONCRETE OF THE LID
AT 0.08 SECOND (BOTTOM/FRONT VIEW) (MPa)

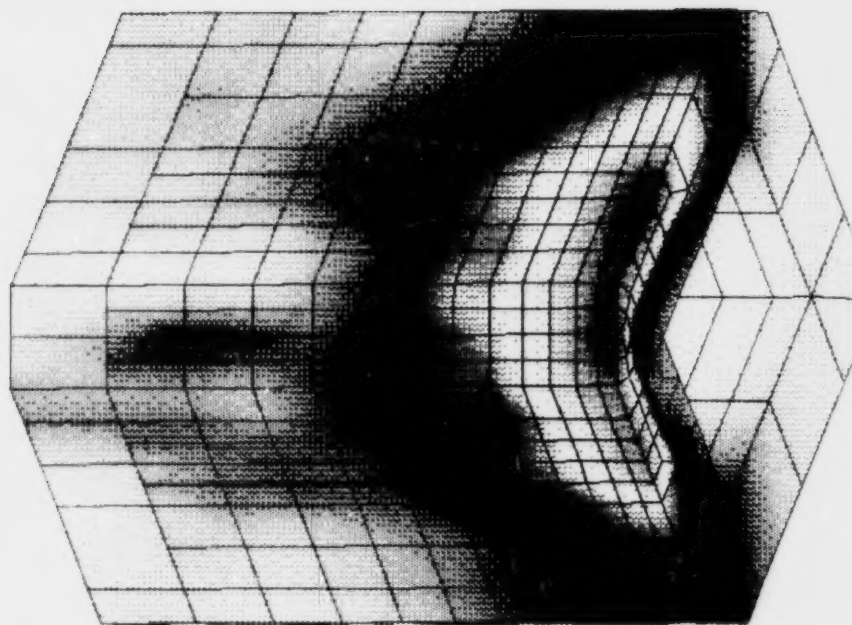
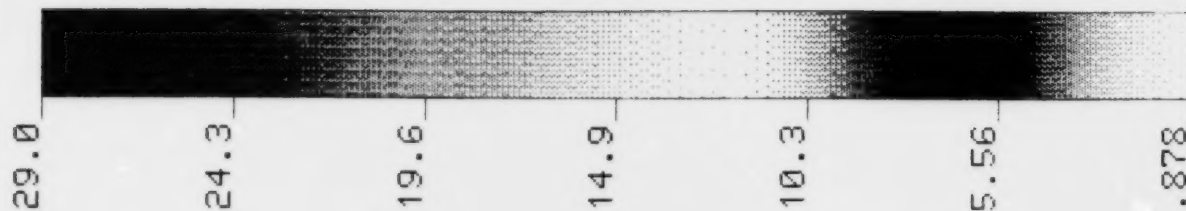
CIC 9M DROP
TIME = 0.08



X
Z Y

FIGURE 51
VON MISES STRESS IN THE CONTAINER OUTER LINER AT
0.08 SECOND (BOTTOM/FRONT VIEW) (MPa)

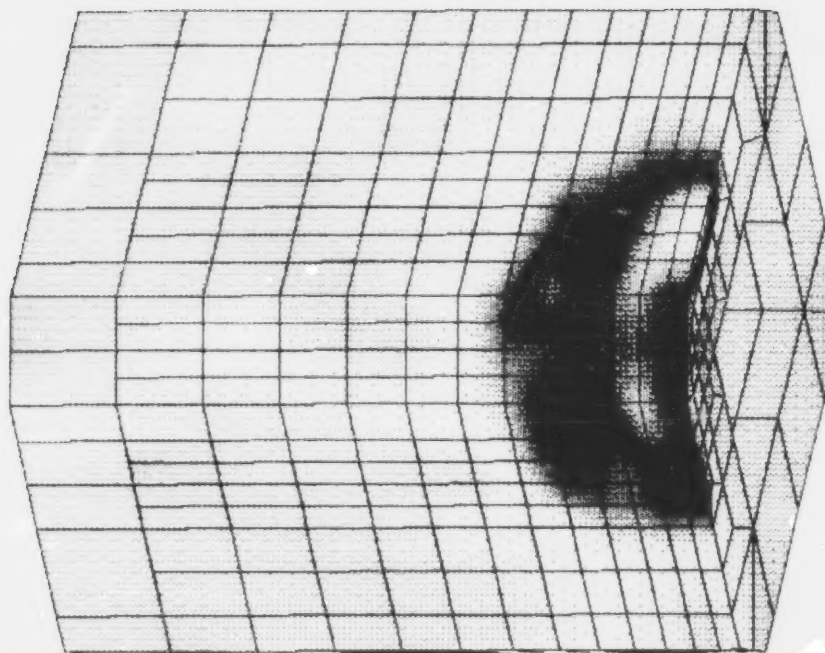
CIC 9M DROP
TIME = 0.08



X
Z
Y

FIGURE 52
CASE 1: EFFECTIVE STRESS IN THE CONTAINER CONCRETE AT
0.08 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME = 0.08



X
Y

FIGURE 53

CASE 1: HYDROSTATIC PRESSURE IN THE CONTAINER CONCRETE
AT 0.08 SECOND (BOTTOM/FRONT VIEW) (mm/mm)

0.08

CIC 9M DROP
TIME =

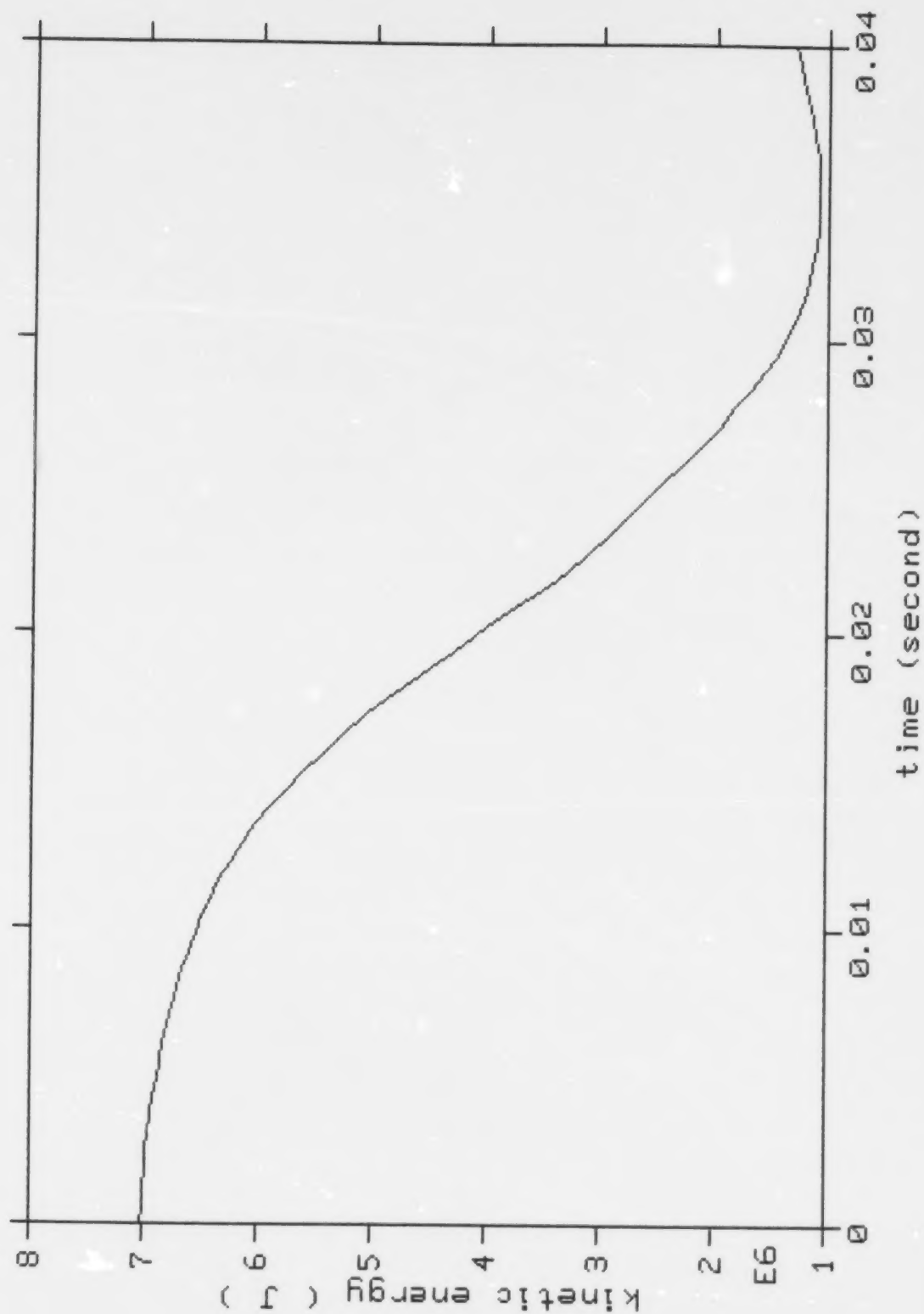


FIGURE 54

CASE 2: KINETIC ENERGY TIME HISTORY OF THE CIC

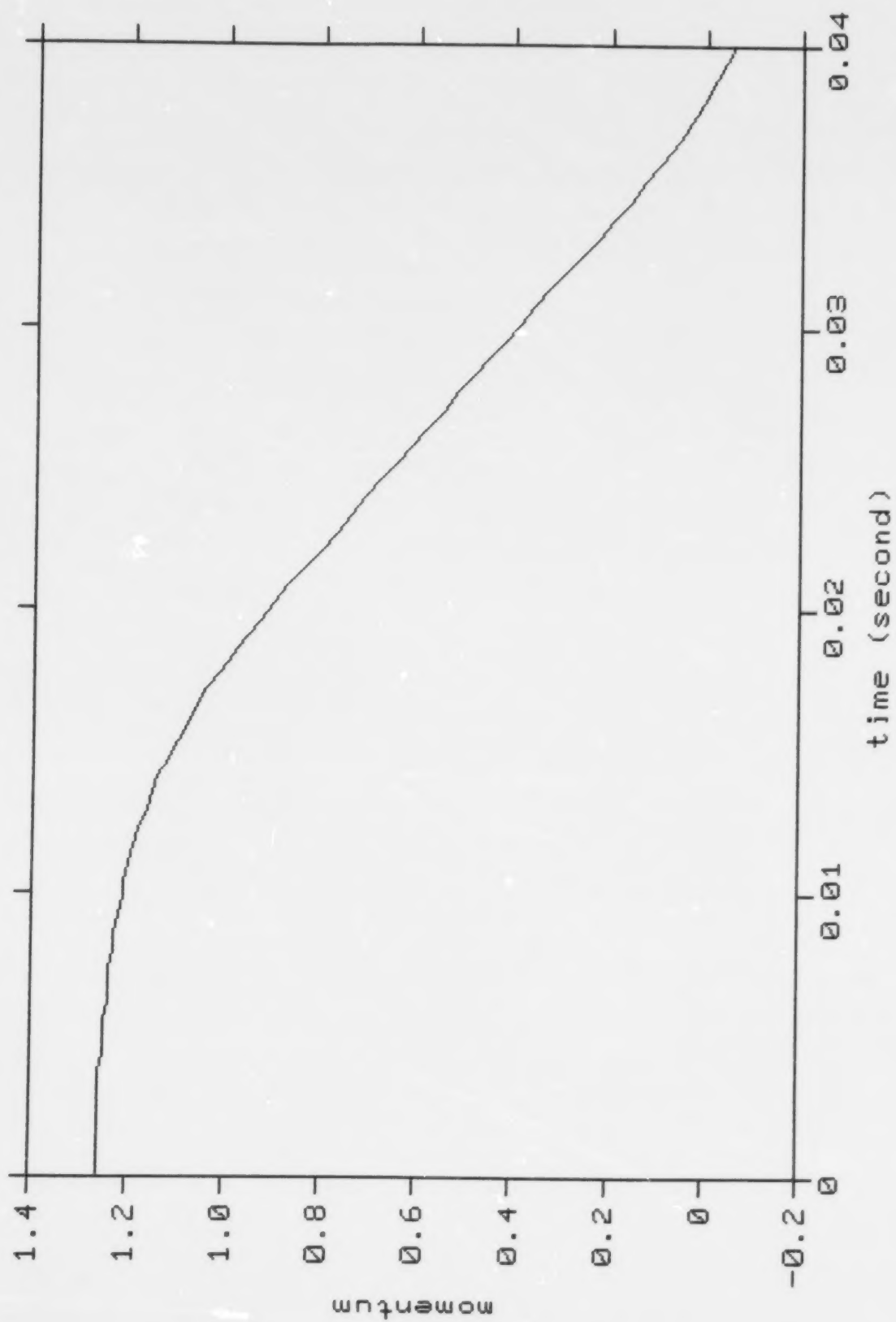


FIGURE 55

CASE 2: NORMALIZED MOMENTUM TIME HISTORY OF THE CIC

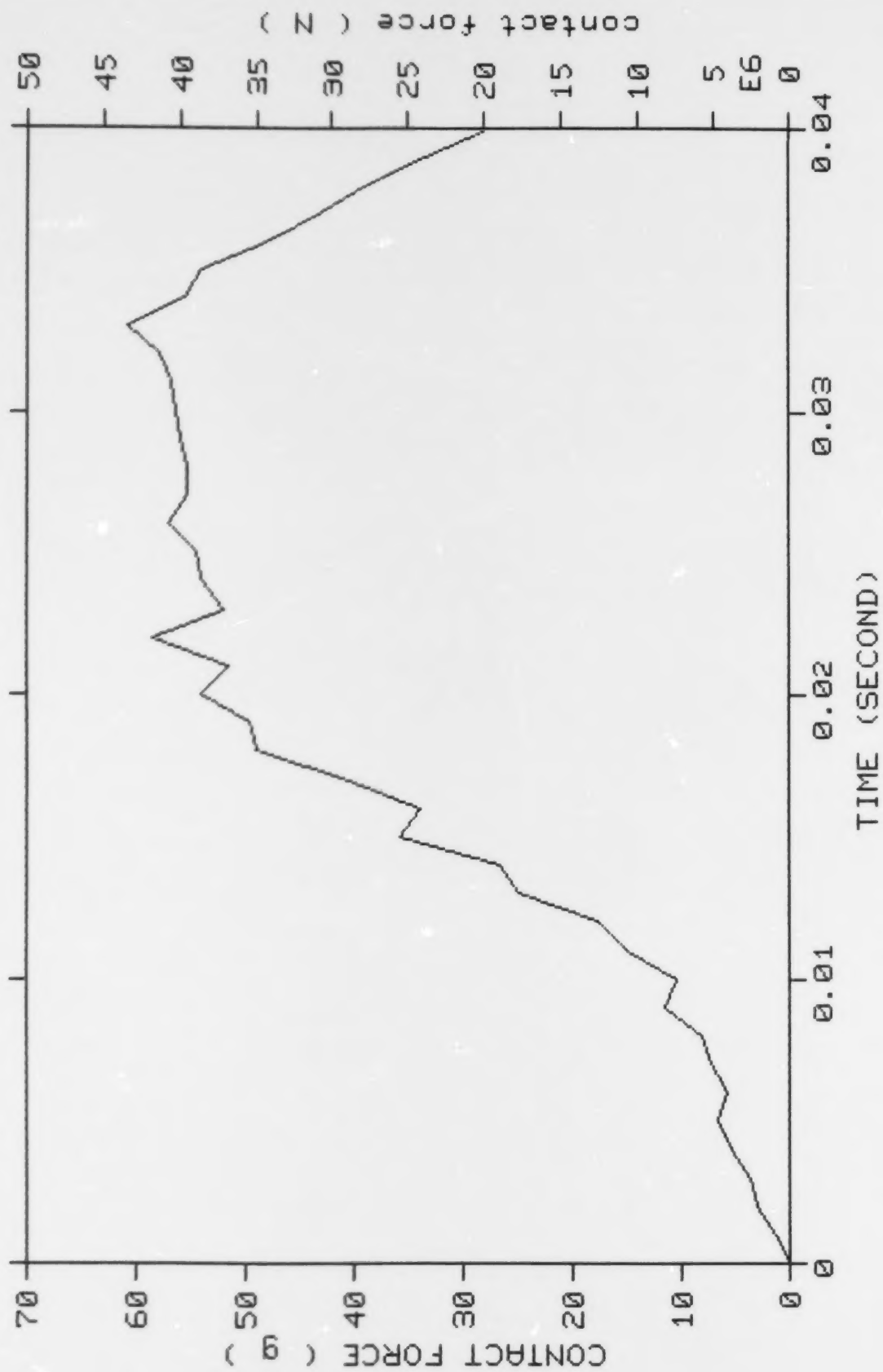


FIGURE 56

CASE 2: CONTACT FORCE TIME HISTORY OF THE CIC

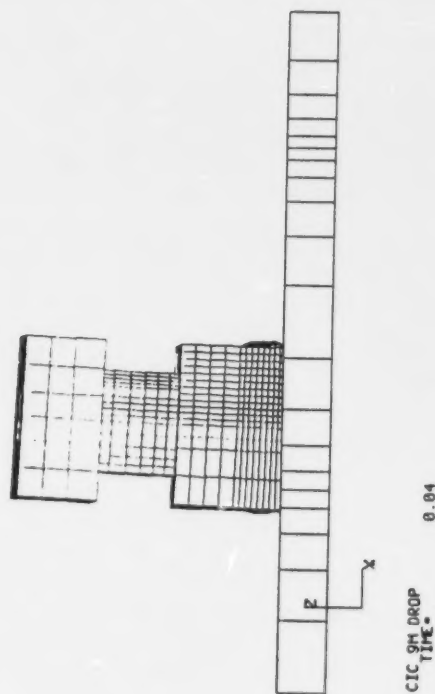
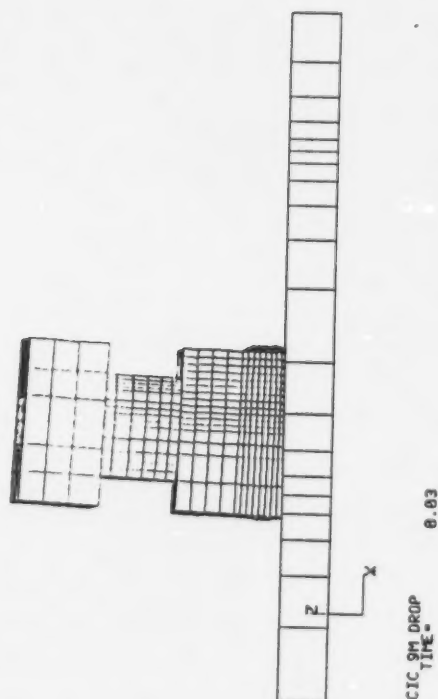
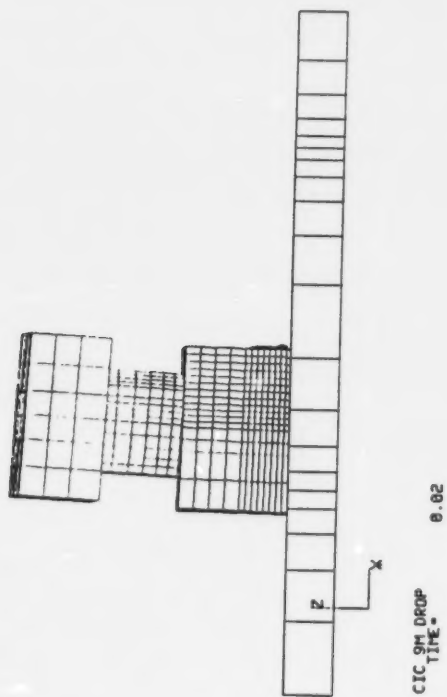
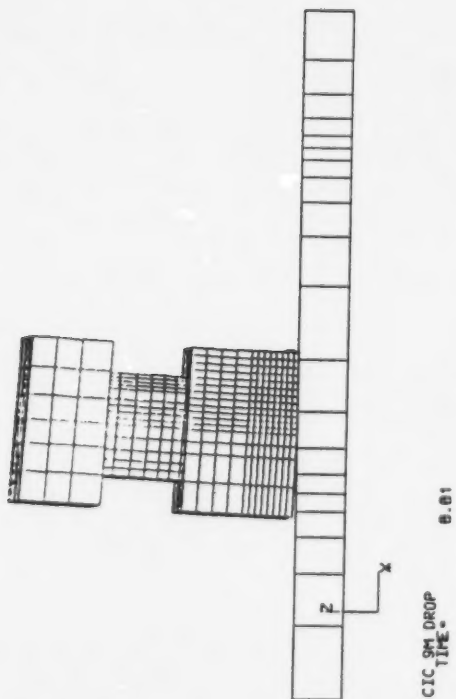


FIGURE 57
CASE 2: SEQUENTIAL DEFORMATION OF THE CIC

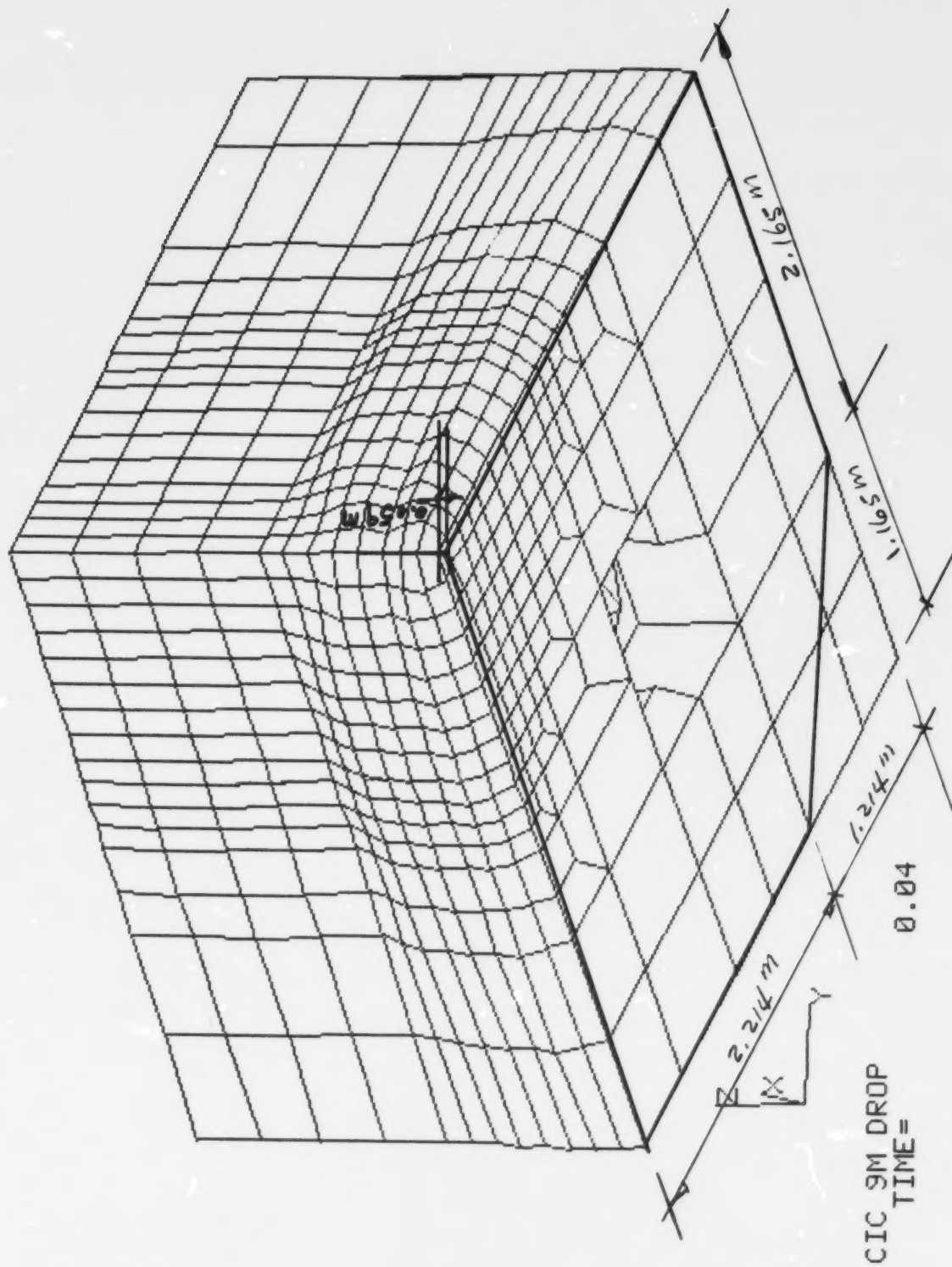


FIGURE 58
CASE 2: FOOTPRINT SIZE OF THE IMPACT LIMITER #1

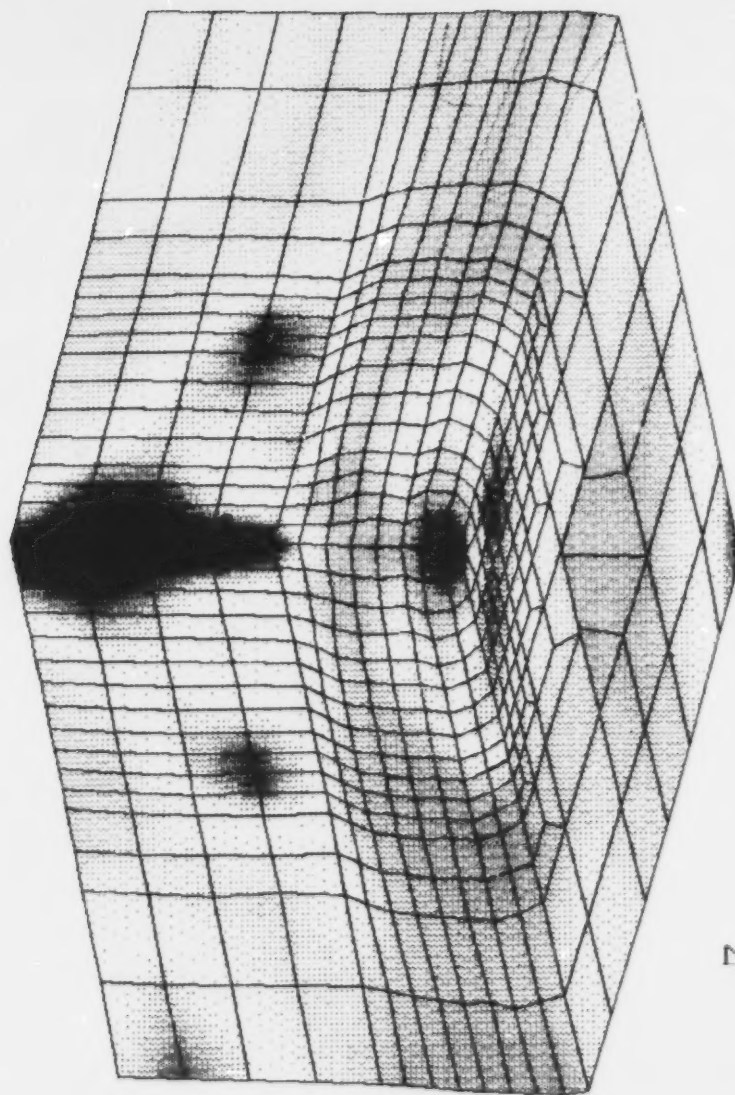
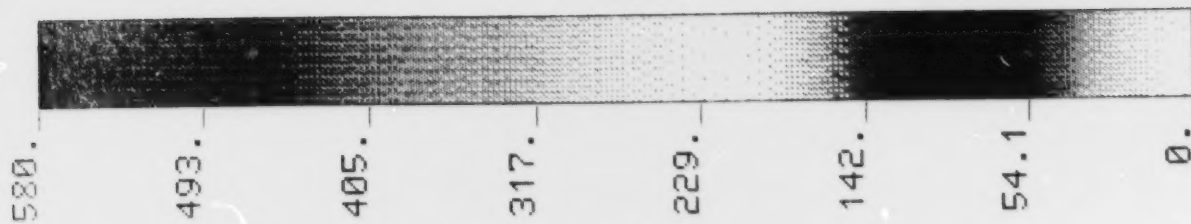


FIGURE 59

CASE 2: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF
THE IMPACT LIMITER #1 AT 0.03 SECOND
(BOTTOM/Front VIEW) (MPa)

CIC 9M DROP

TIME= 0.03

MAX DISP= 0.4513030E+00 AT NODE 432 AT Z DIRECTION

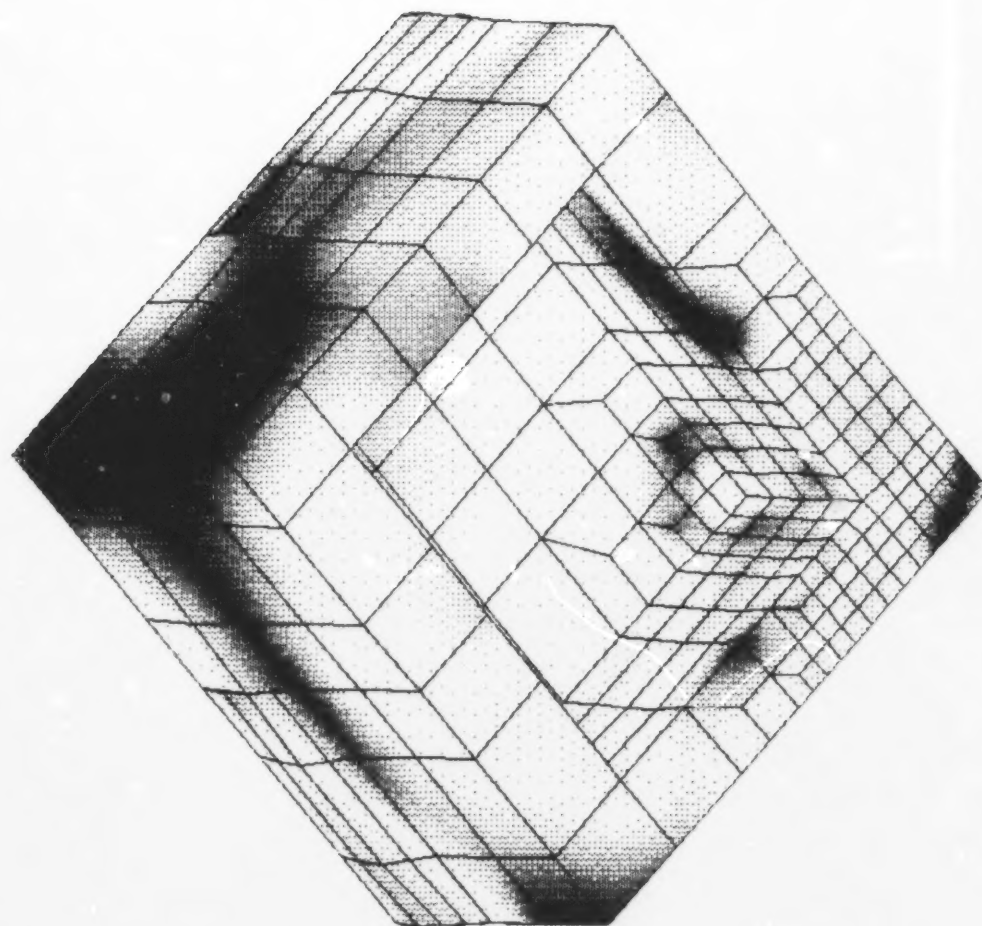
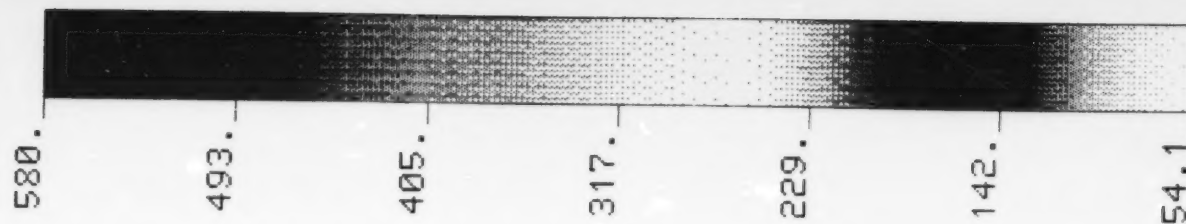


FIGURE 60

CASE 2: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER AT 0.03 SECOND (TOP/REAR VIEW) (MPa)

0.03



CIC 9M DRDP
TIME = X

307.
265.
223.
181.
138.
96.3
54.1

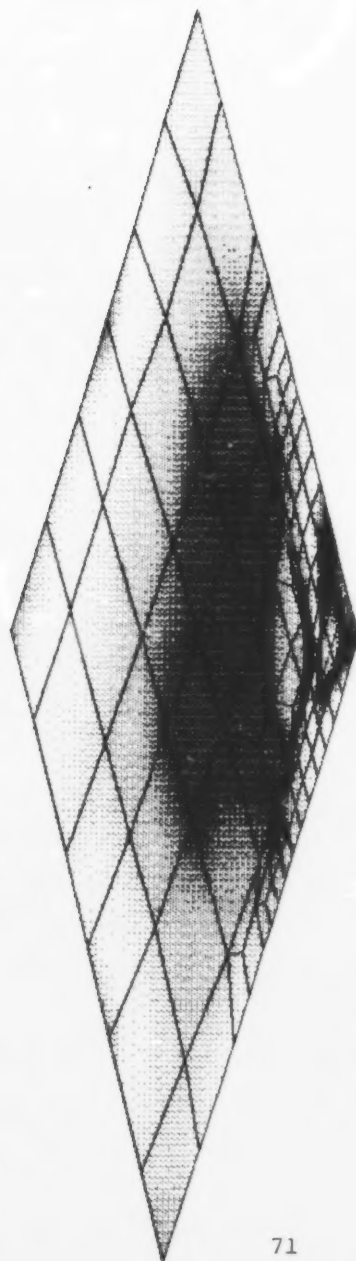


FIGURE 61

CASE 2: VON MISES STRESS IN THE INSIDE HORIZONTAL STAINLESS STEEL
PLATE OF THE IMPACT LIMITER #1 AT 0.03 SECOND (MPa)

CIC 9M DROP
TIME=

0.03

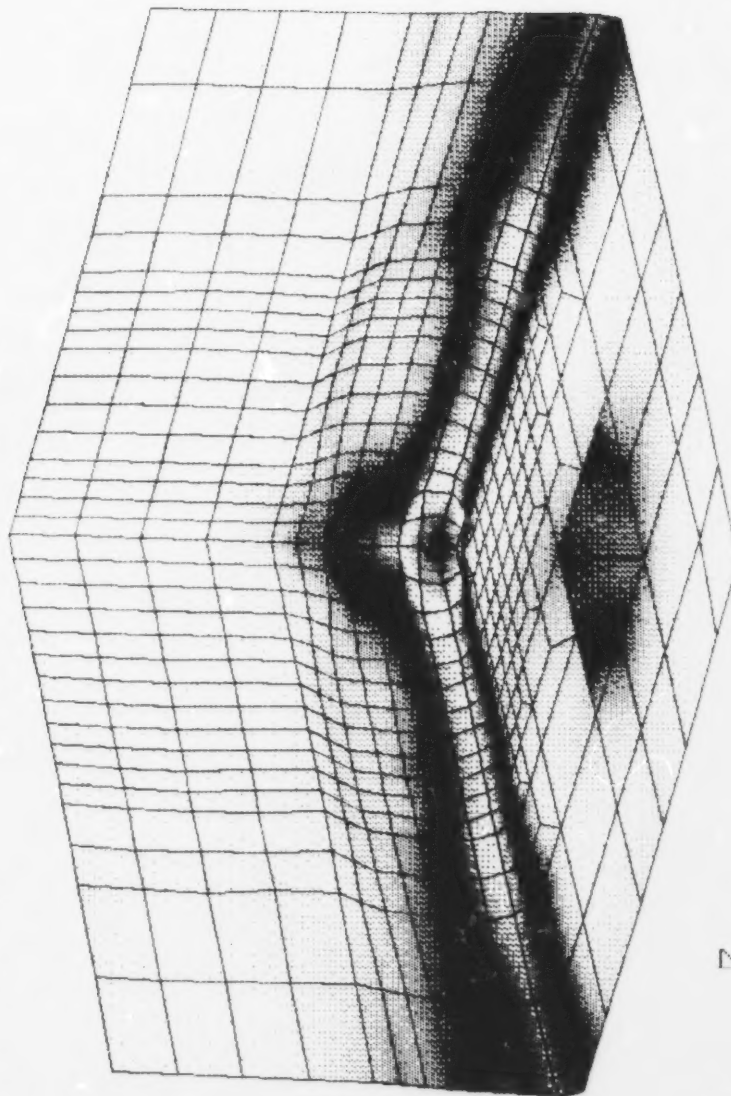
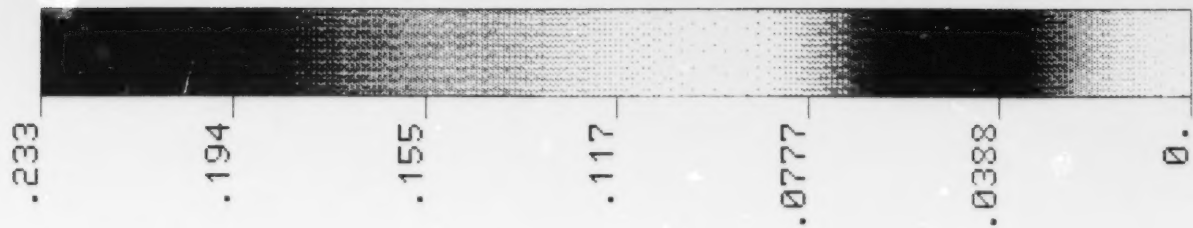


FIGURE 62

CASE 2: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE STAINLESS STEEL
SKIN OF THE IMPACT LIMITER #1 AT 0.03 SECOND
(BOTTOM/FRONT VIEW) (mm/mm)

CIC 9M DROP
TIME =

0.03

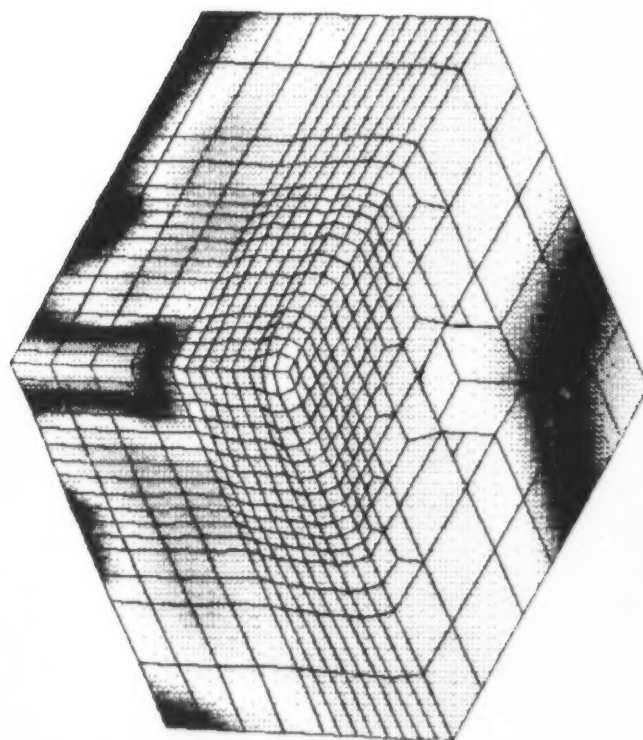
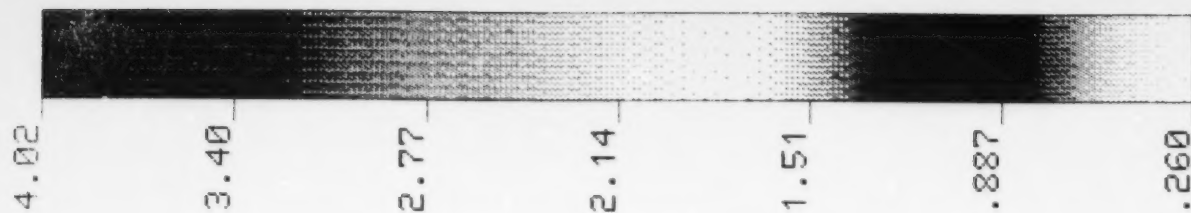
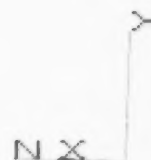


FIGURE 63

CASE 2: EFFECTIVE STRESS IN THE RIGID FOAM OF THE IMPACT LIMITER #1
AT 0.02 SECOND (BOTTOM/Front VIEW) (MPa)

CIC 9M DROP
TIME = 0.02



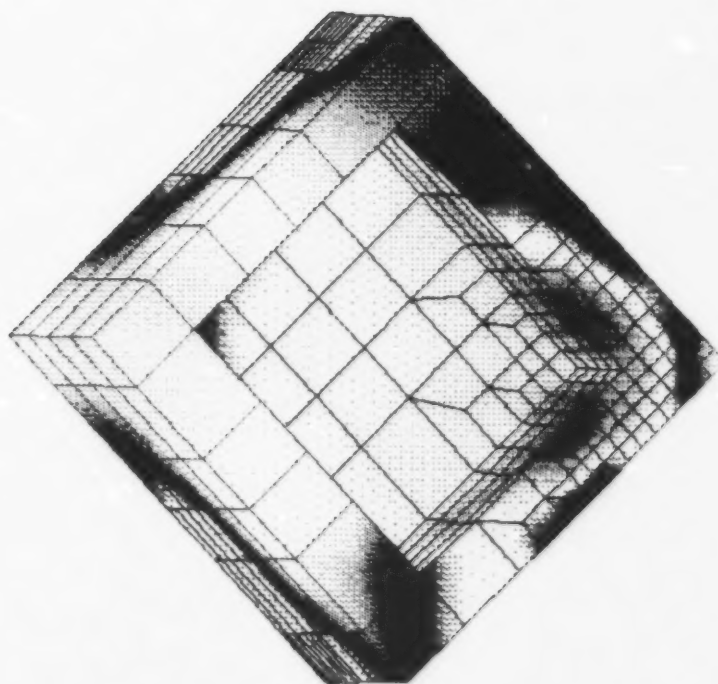
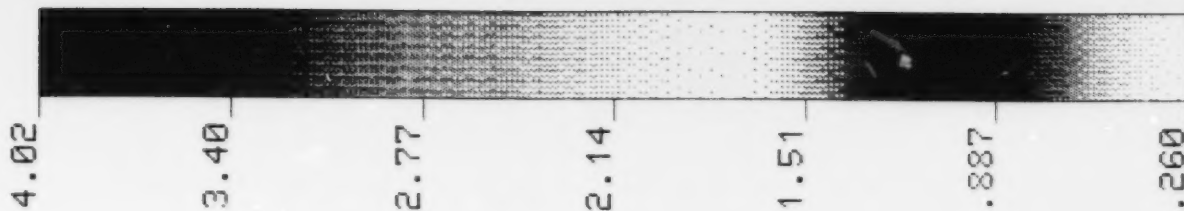


FIGURE 64

CASE 2: EFFECTIVE STRESS IN THE RIGID FOAM OF THE IMPACT LIMITER #1
AT 0.02 SECOND (TOP/REAR VIEW) (MPa)

0.02



CIC 9M DROP
TIME = X

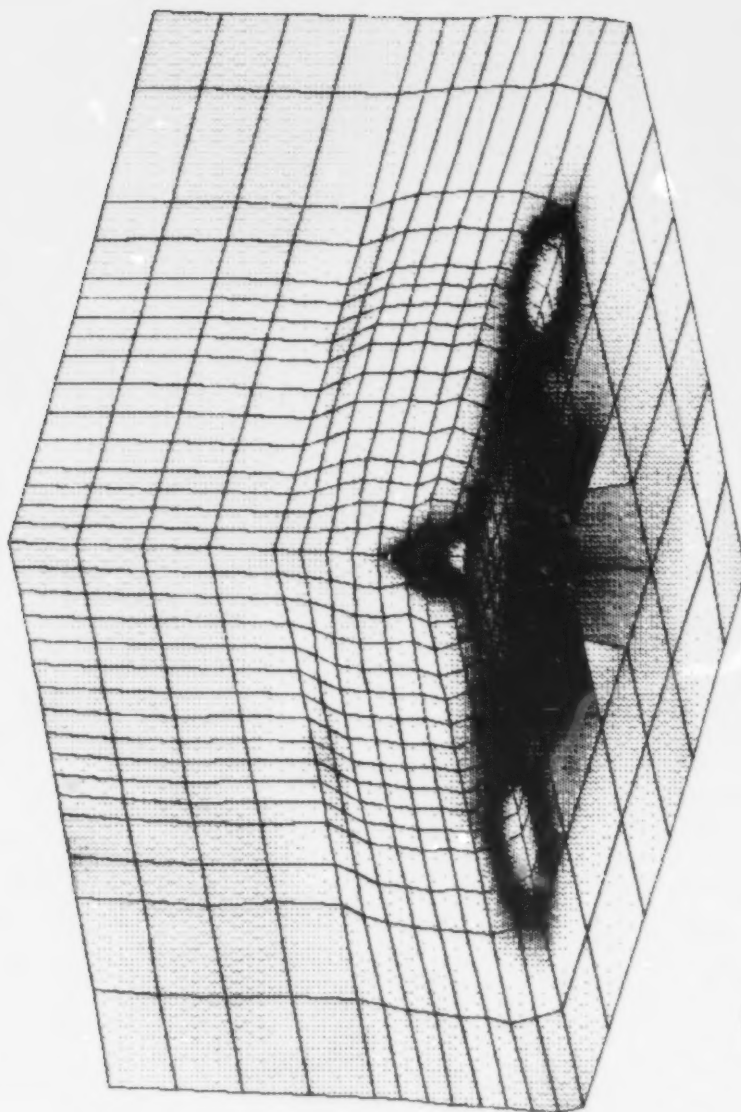
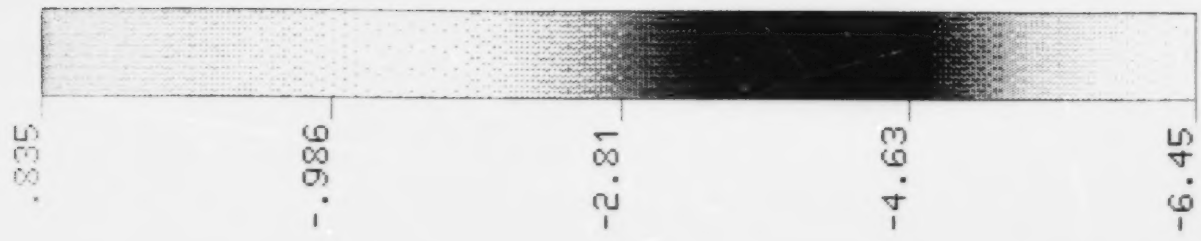


FIGURE 65

CASE 2: HYDROSTATIC PRESSURE IN THE RIGID FOAM OF THE IMPACT LIMITER
#1 AT 0.03 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME = 0.03

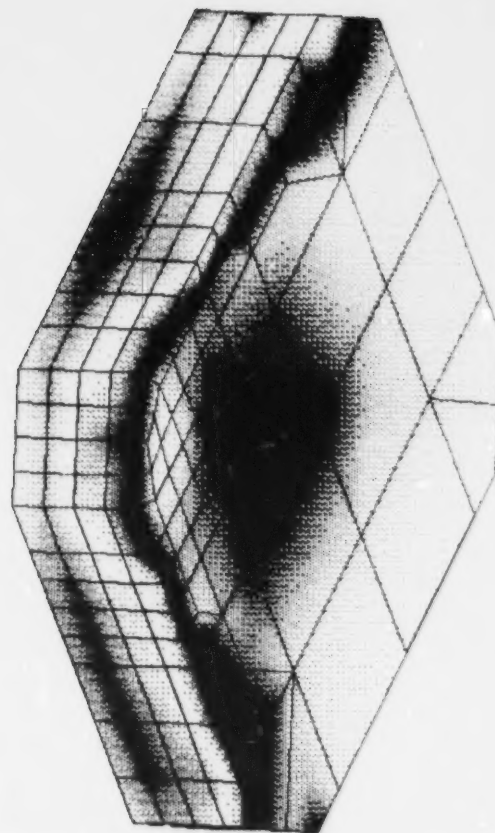
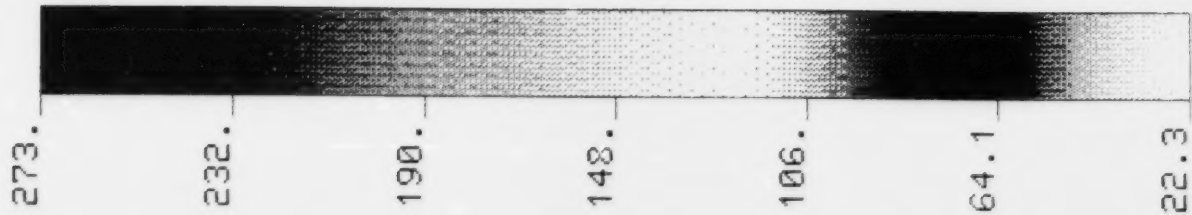


FIGURE 66
CASE 2: VON MISES STRESS IN THE LID PLATES AT 0.02 SECOND
(BOTTOM/Front VIEW) (MPa)

CIC 9M DROP
TIME = 0.02

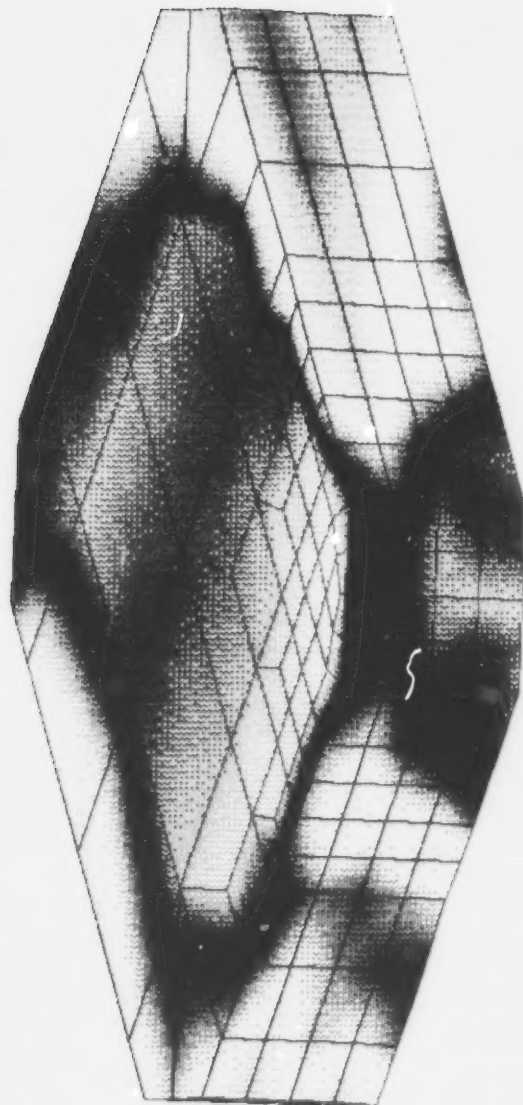
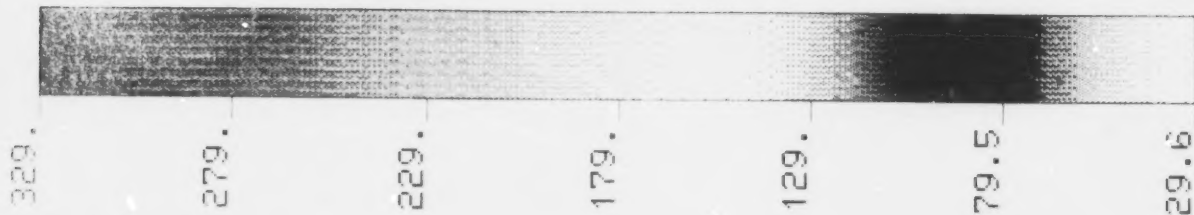


FIGURE 67

CASE 2: VON MISES STRESS IN THE LID PLATES AT 0.03 SECOND
(TOP/FRONT VIEW) (MPa)

CIC 9M DROP

TIME= 0.03

MAX DISP= 0.4513030E+00 AT NODE 432 AT Z DIRECTION

.0261

.0218

.0174

.0131

.00871

.00436

.0000176

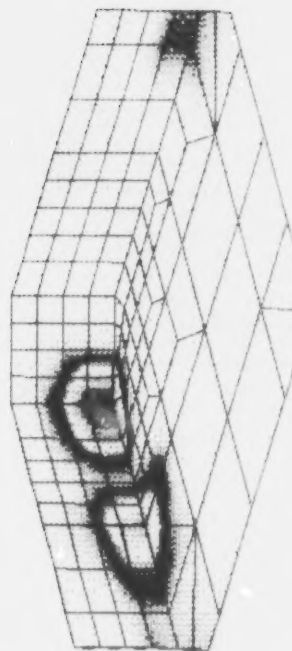


FIGURE 68

CASE 2: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN
THE LID PLATES AT 0.04 SECOND (BOTTOM/FRONT VIEW) (mm/mm)

Z
X Y

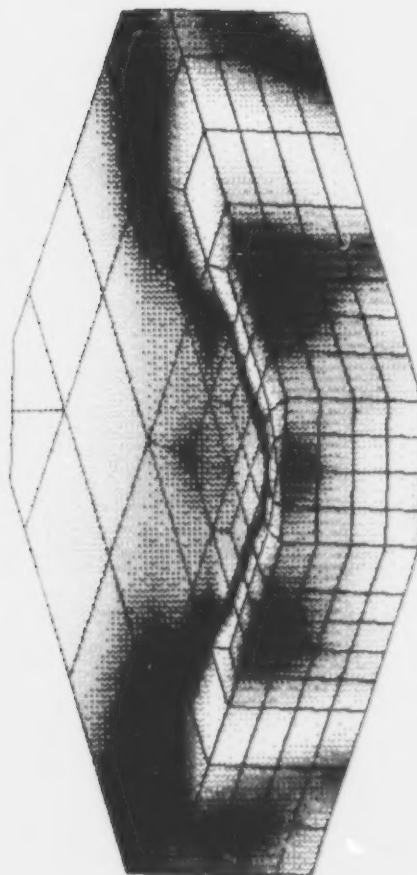
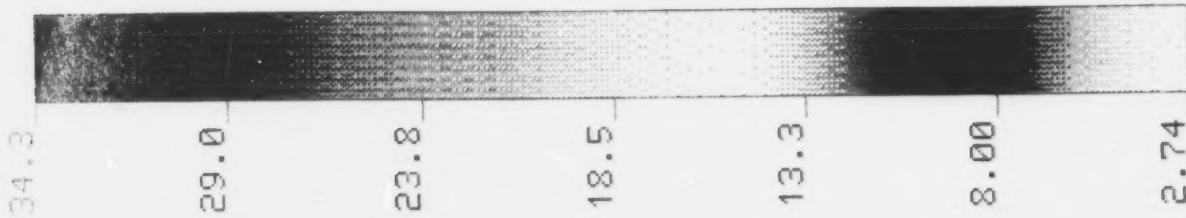


FIGURE 69

CASE 2: EFFECTIVE STRESS IN THE CONCRETE OF THE LID AT
0.02 SECOND (TOP/FRONT VIEW) (MPa)



CIC 9M DROP
TIME = 0.02

.0192

.0160

.0128

.00959

.00640

.00321

.0000242

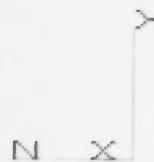
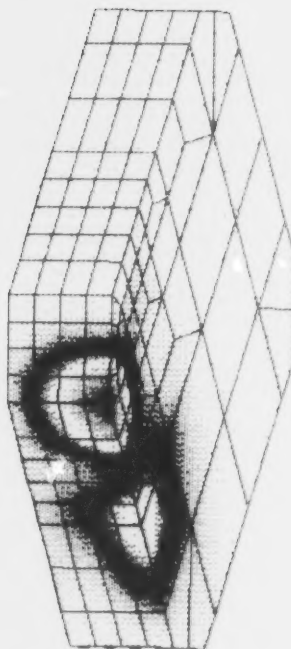


FIGURE 70

CASE 2: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
CONCRETE OF THE LID AT 0.04 SECOND
(BOTTOM/Front VIEW) (mm/mm)

CIC_9M_DROP
TIME =

0.04

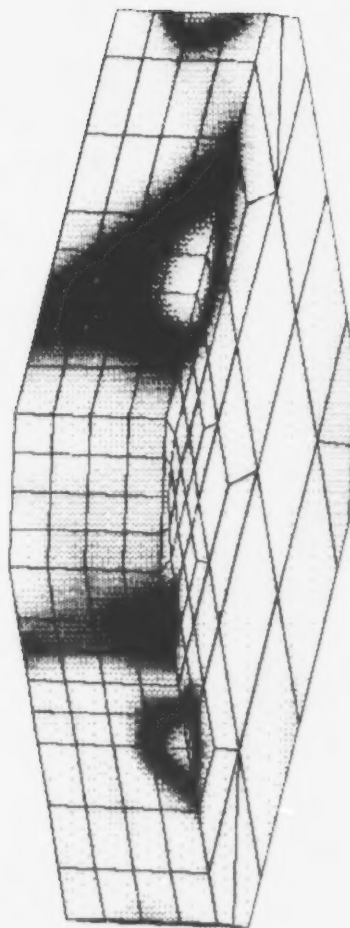


FIGURE 71

CASE 2: HYDROSTATIC PRESSURE IN THE CONCRETE OF THE
LID AT 0.03 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.03

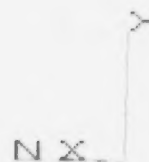
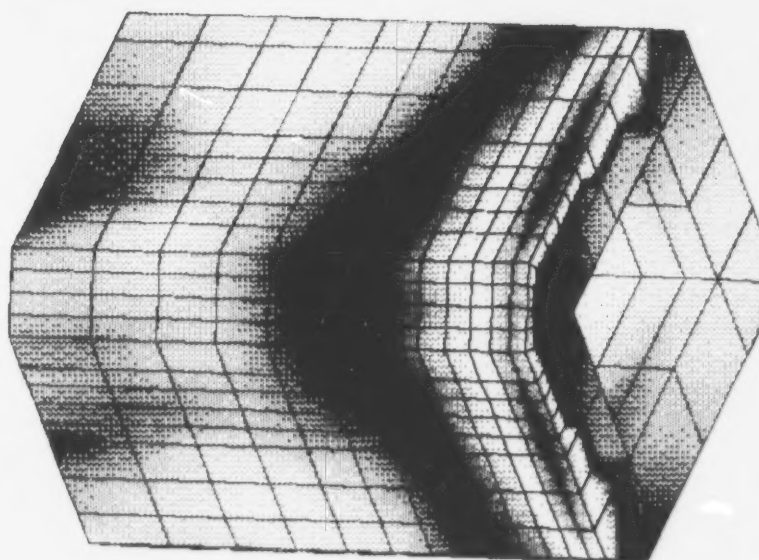
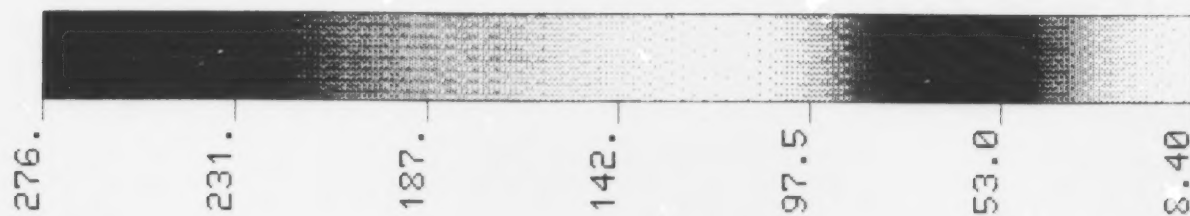


FIGURE 72

CASE 2: VON MISES STRESS IN THE CONTAINER OUTER LINER AT
0.02 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.02

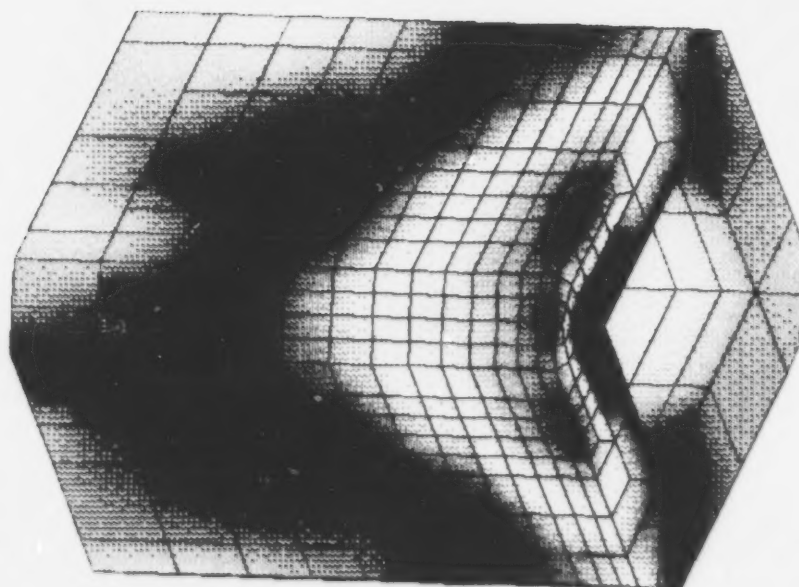
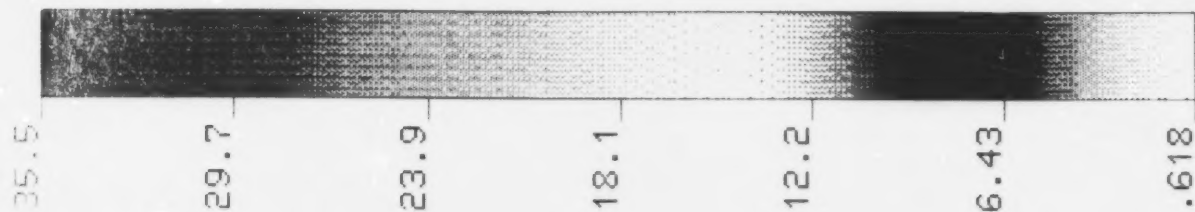
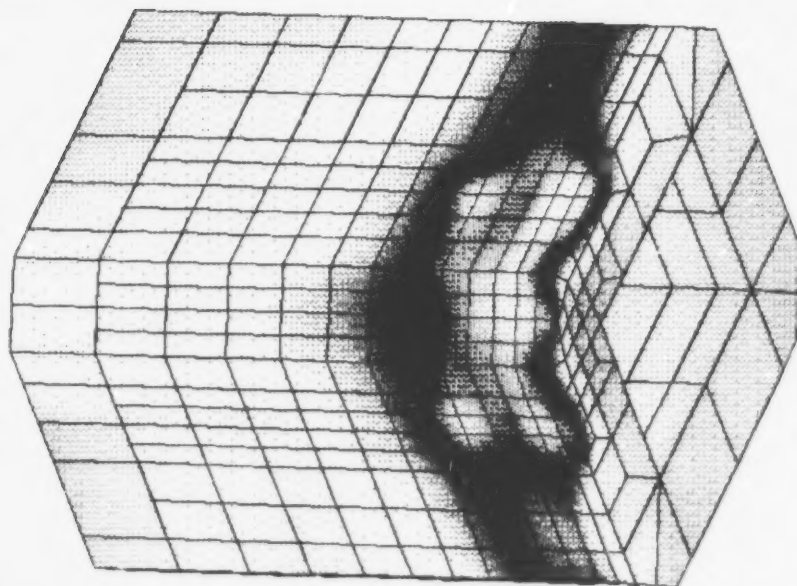
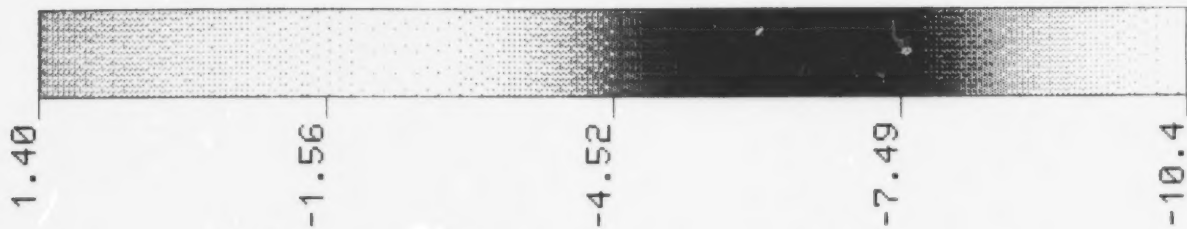


FIGURE 73

CASE 2: EFFECTIVE STRESS IN THE CONTAINER CONCRETE AT
0.02 SECOND (BOTTOM/FRONT VIEW) (MPa)

0.02

CIC_9M_DROP
TIME =



Z
X
Y

FIGURE 74

CASE 2: HYDROSTATIC PRESSURE IN THE CONTAINER CONCRETE
AT 0.02 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC_9M_DROP
TIME =

0.02

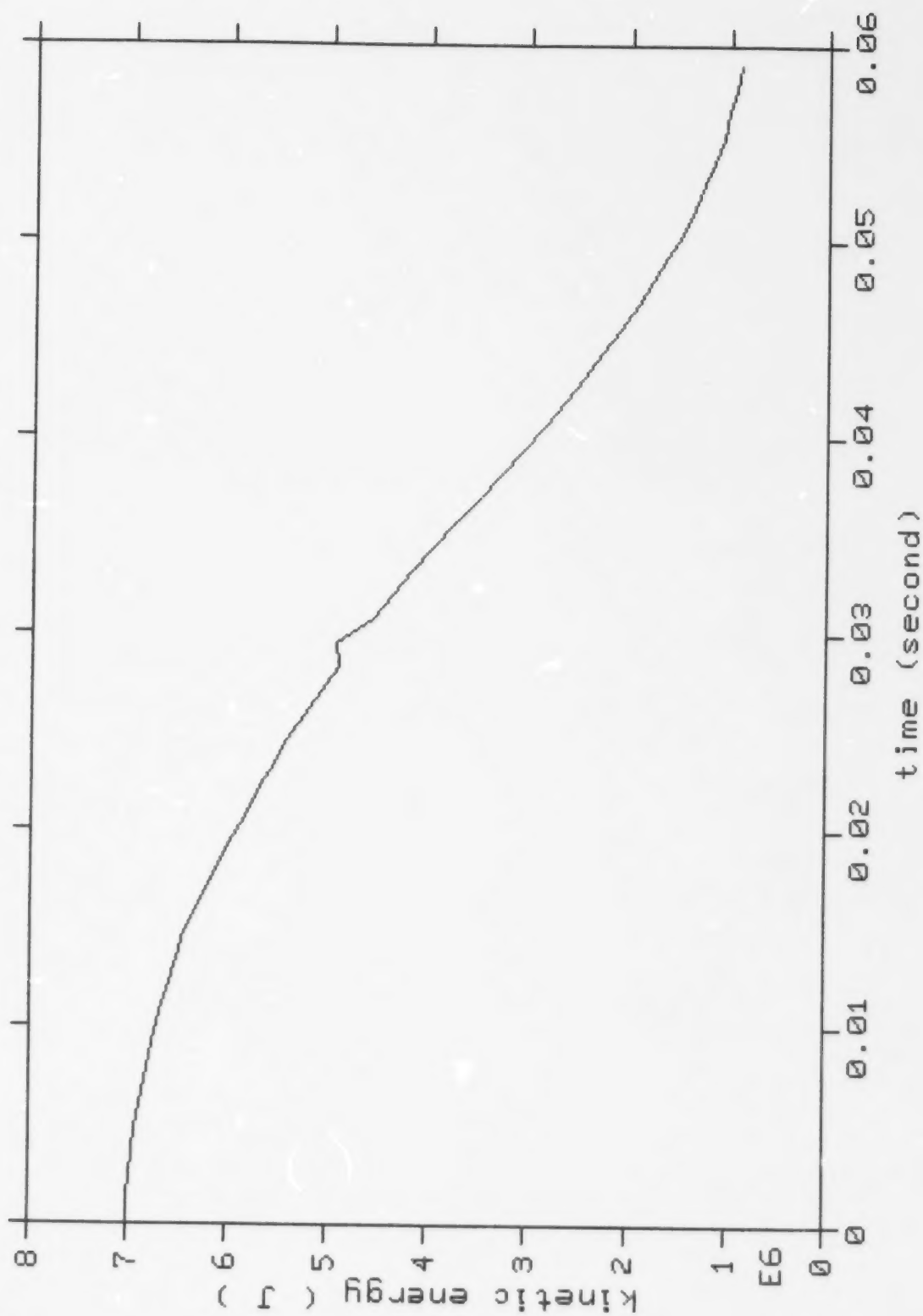


FIGURE 75

CASE 3: KINETIC ENERGY TIME HISTORY OF THE CIC

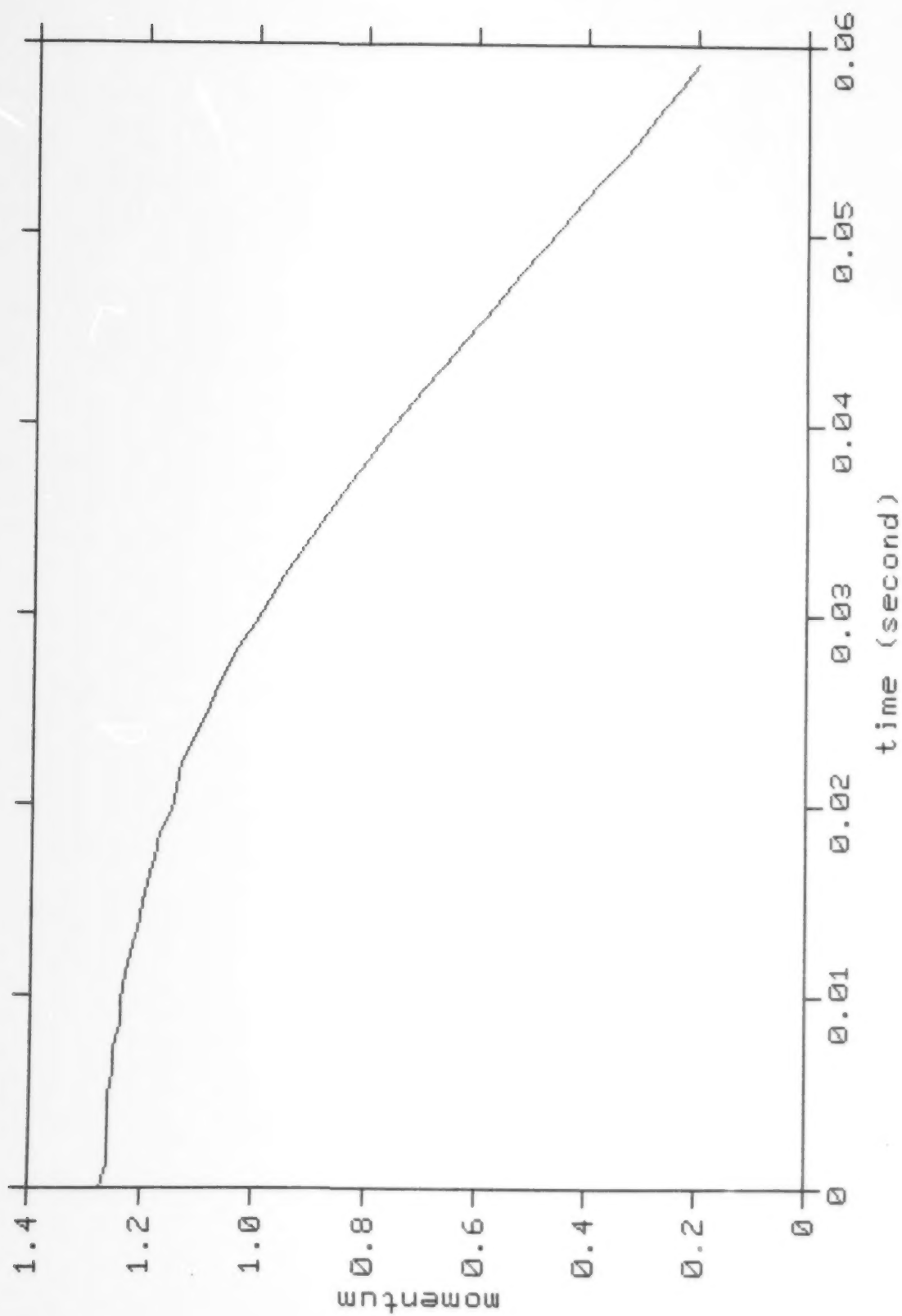


FIGURE 76

CASE 3: NORMALIZED MOMENTUM TIME HISTORY OF THE CIC

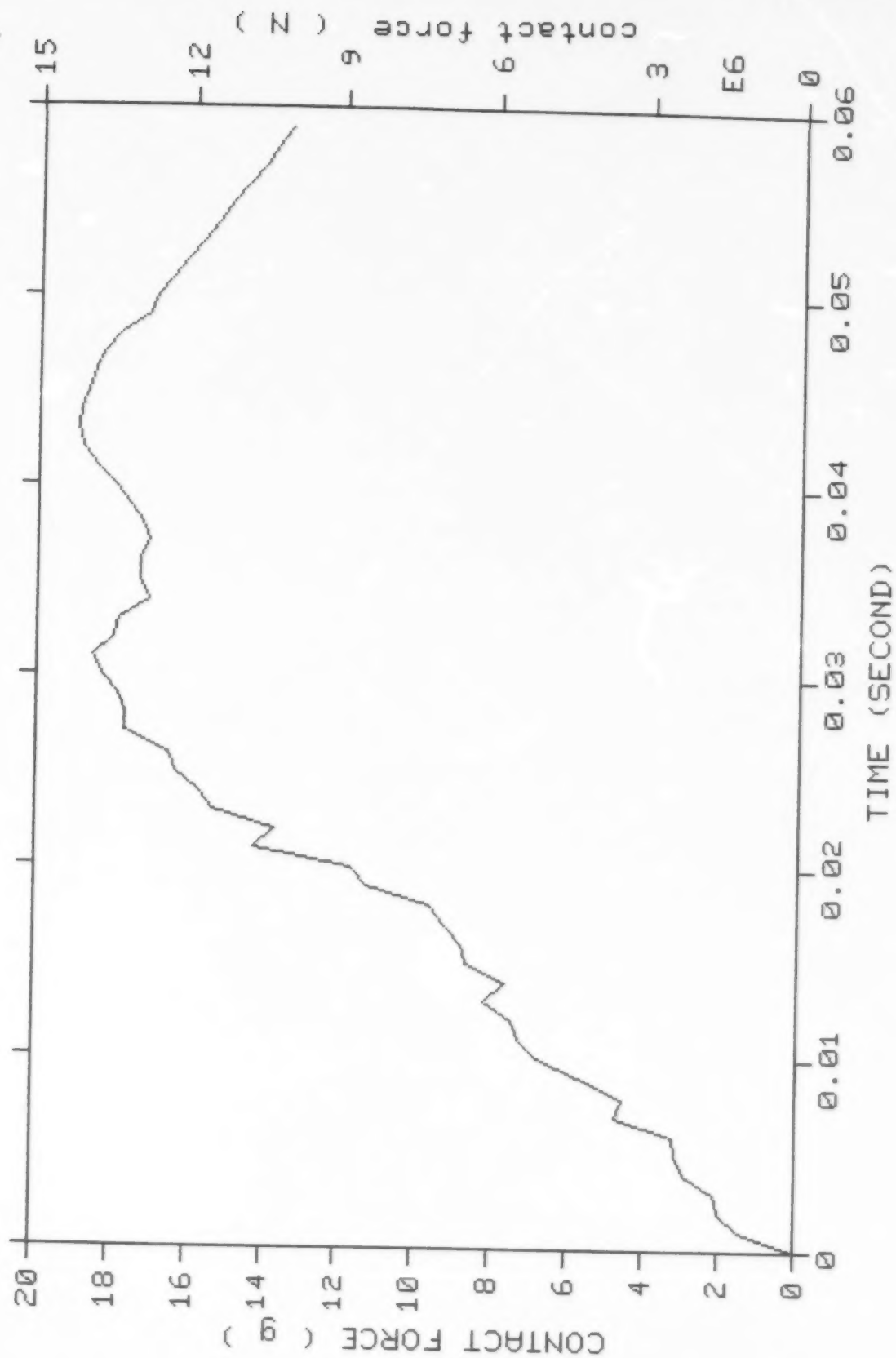


FIGURE 77

CASE 3: CONTACT FORCE TIME HISTORY OF THE IMPACT LIMITER #1

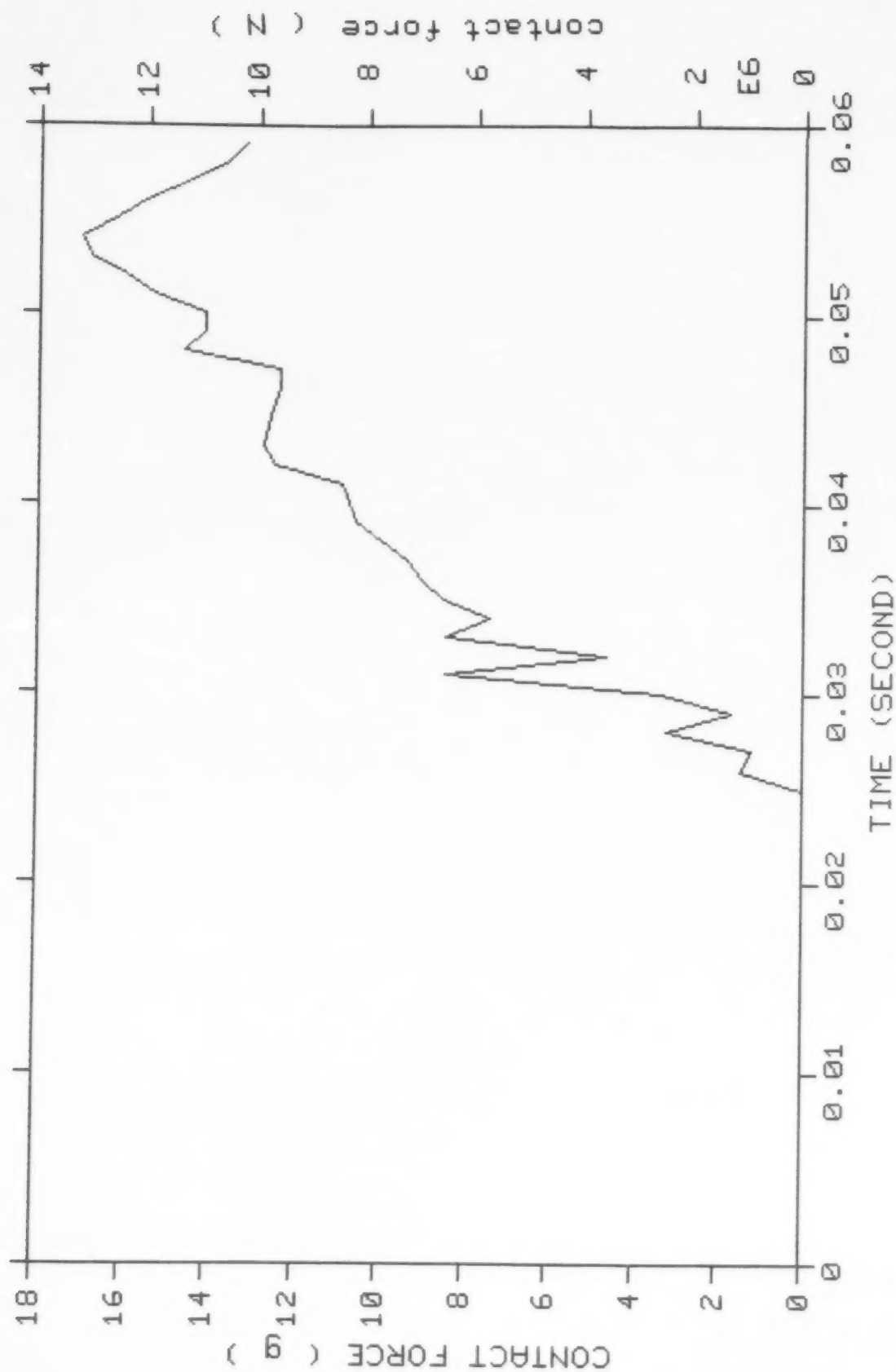


FIGURE 78

CASE 3: CONTACT FORCE TIME HISTORY OF THE IMPACT LIMITER #2

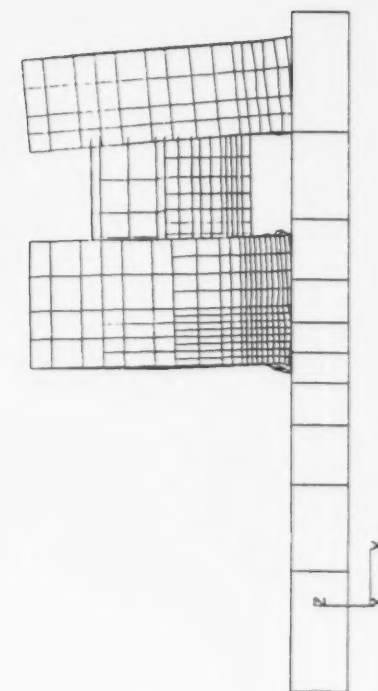
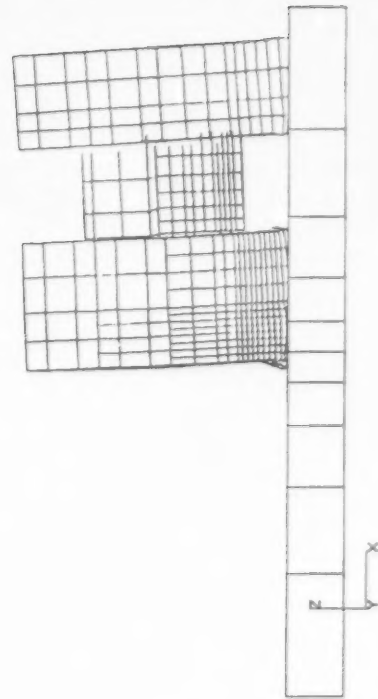
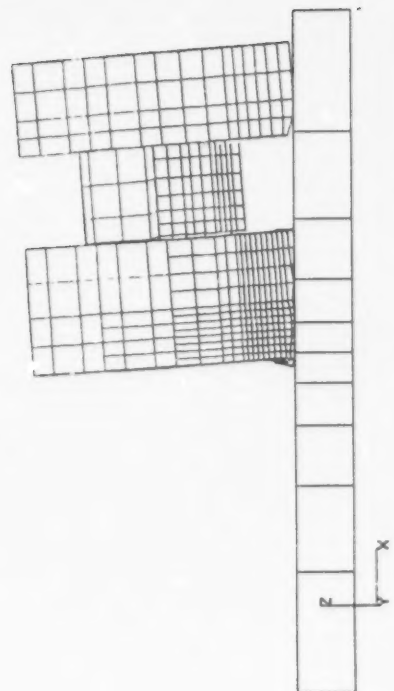
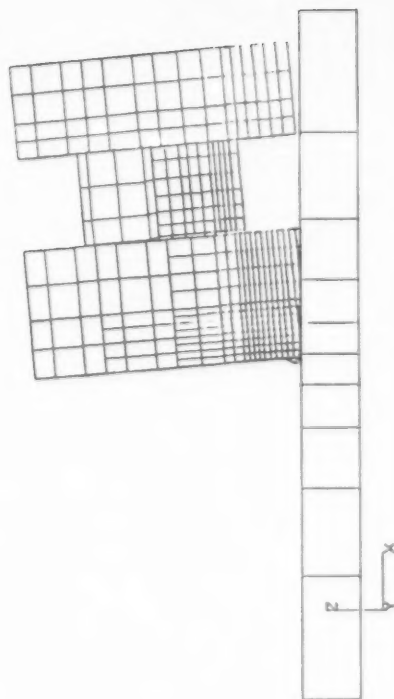
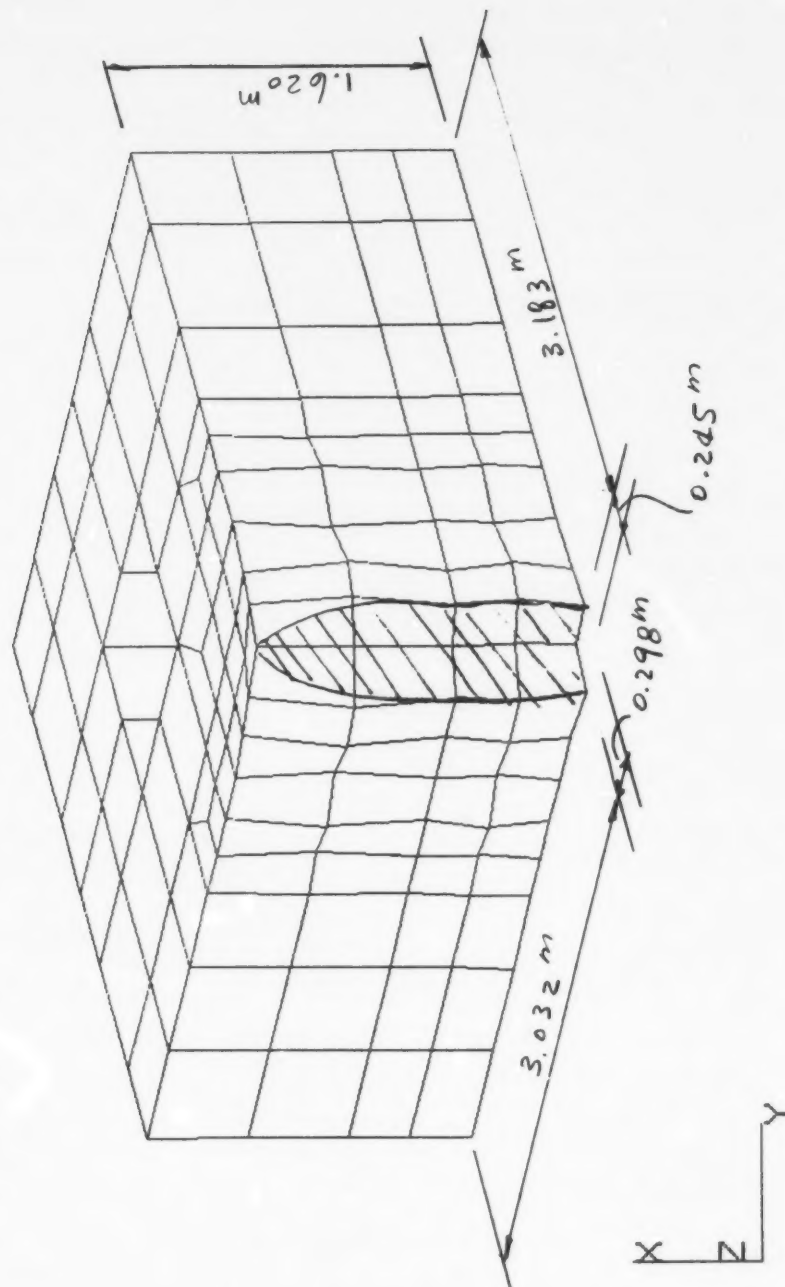


FIGURE 79
CASE 3: SEQUENTIAL DEFORMATION OF THE CIC



CIC 9M DROP
TIME =

0.05

FIGURE 81

CASE 3: FOOTPRINT SIZE OF THE IMPACT LIMITER #2

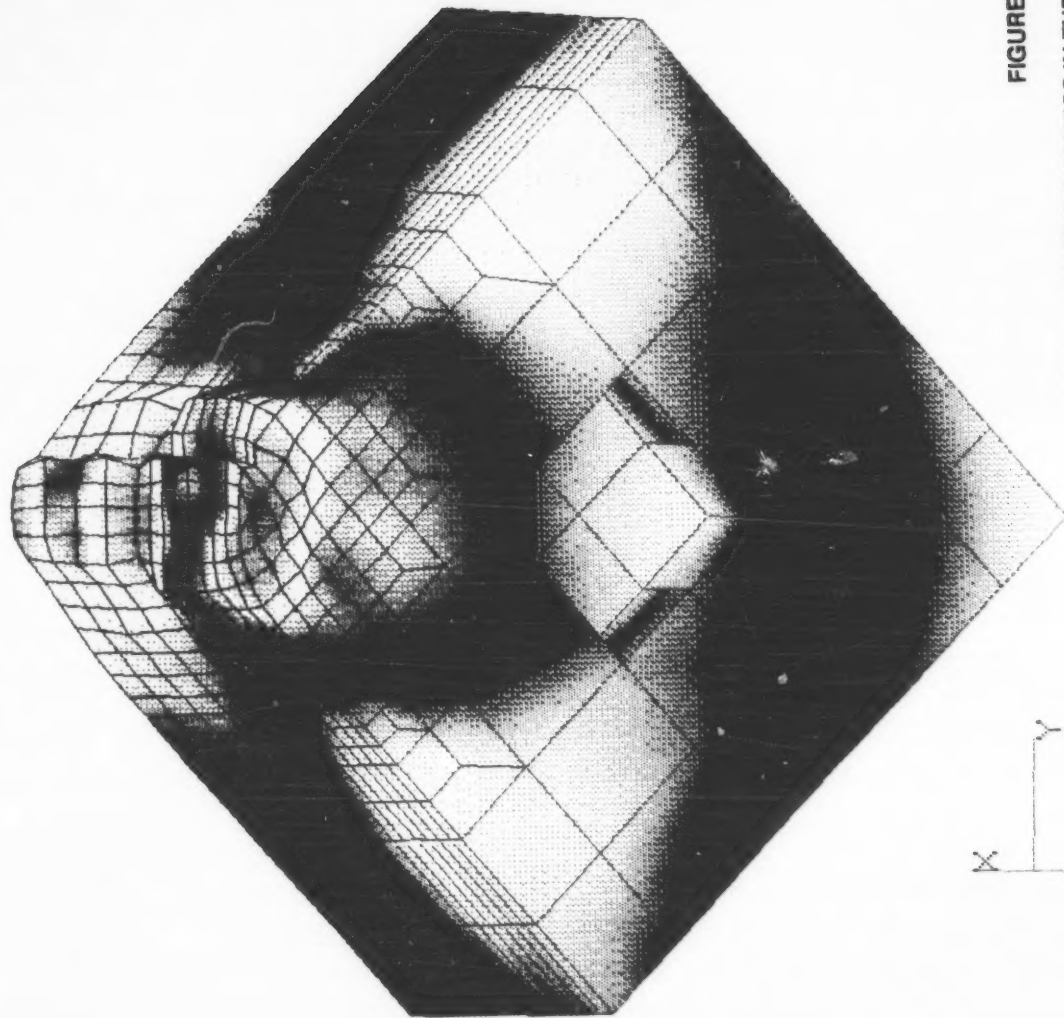
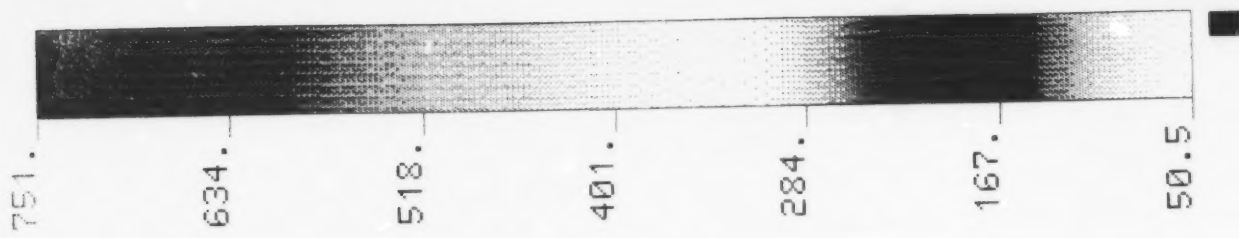


FIGURE 82

CASE 3: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #1 AT 0.04 SECOND
(BOTTOM/FRONT VIEW) (MPa)

CIC 9M DRDP 0.04
TIME = 0.04
MAX DISP = 0.5545060E+00 AT NODE 2467 AT Z DIRECTION

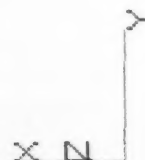
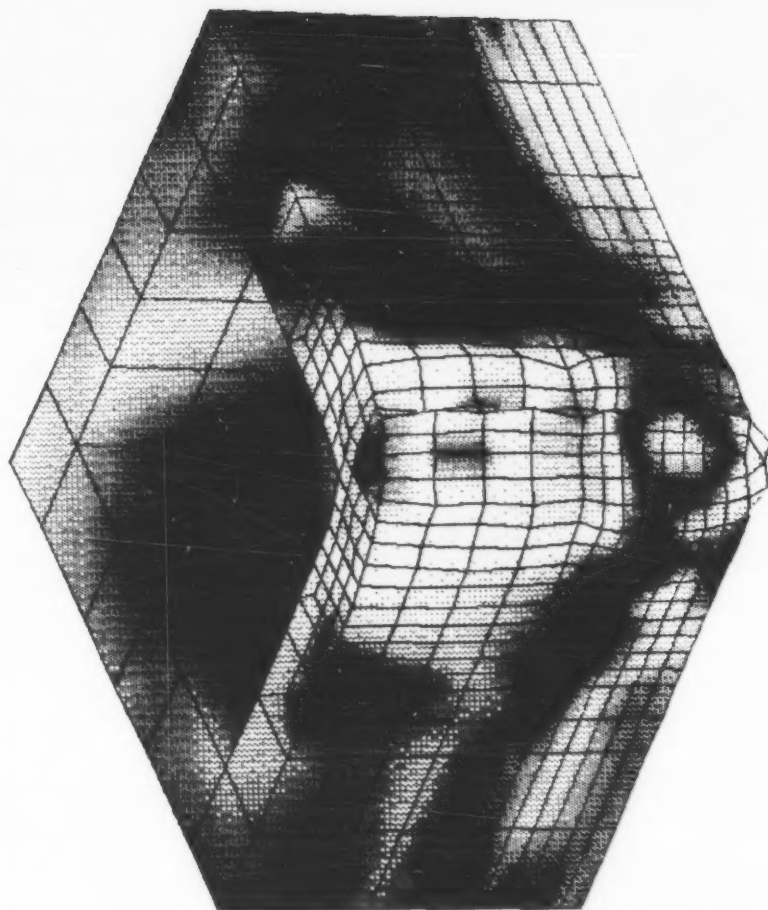
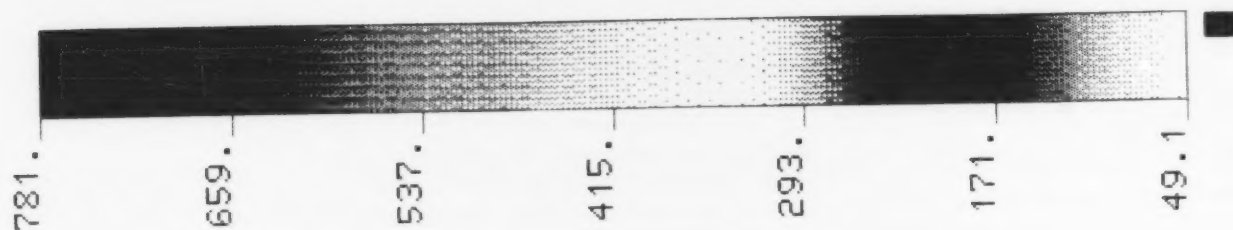


FIGURE 83

CASE 3: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #1 AT 0.05 SECOND
(FRONT VIEW) (MPa)

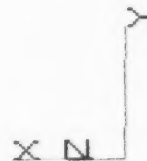
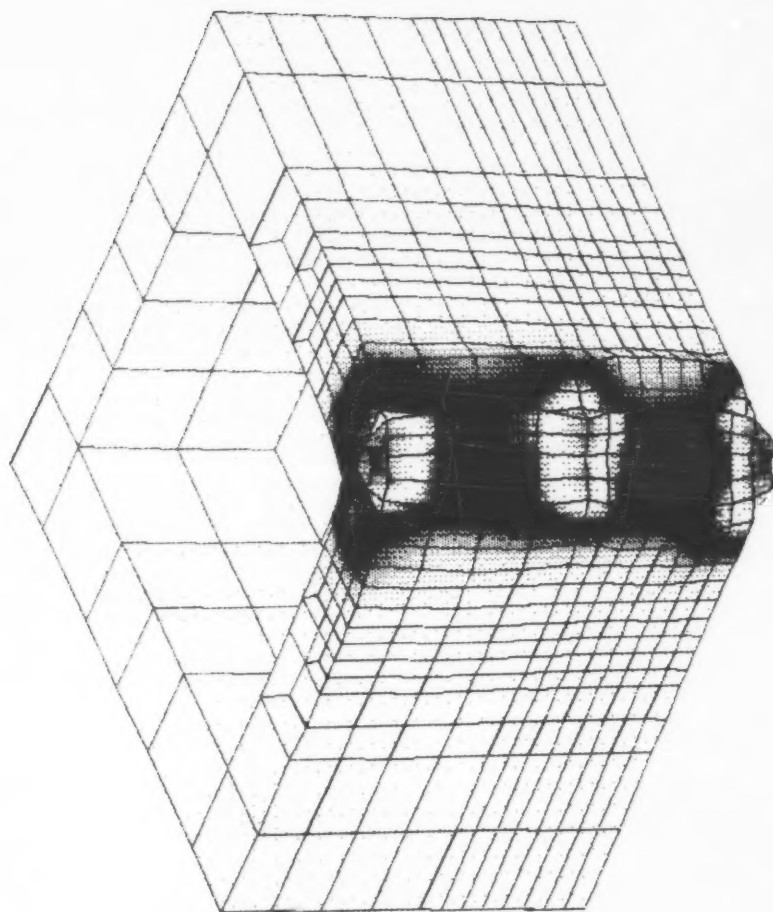
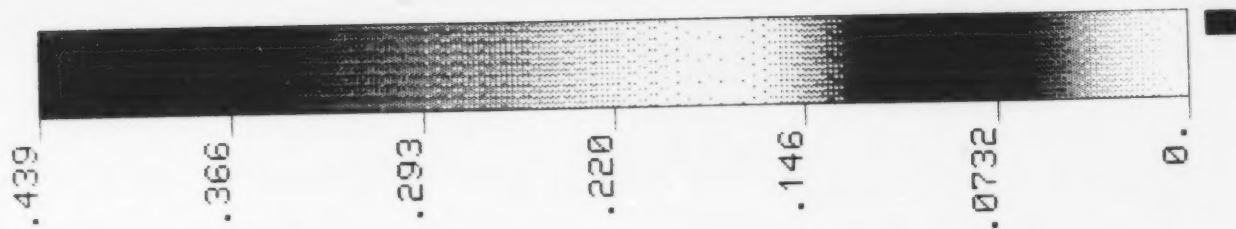


FIGURE 84

CASE 3: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
STAINLESS STEEL SKIN OF THE IMPACT LIMITER #1 AT
0.05 SECOND (FRONT VIEW) (mm/mm)

CIC_9M_DROP
TIME =

0.05

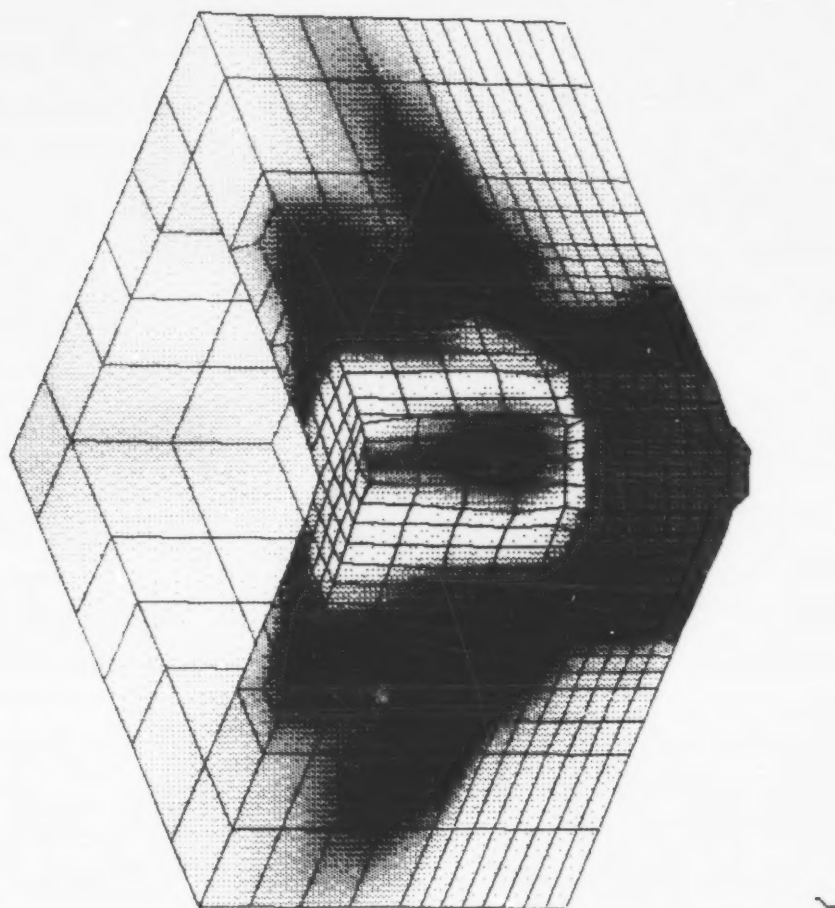
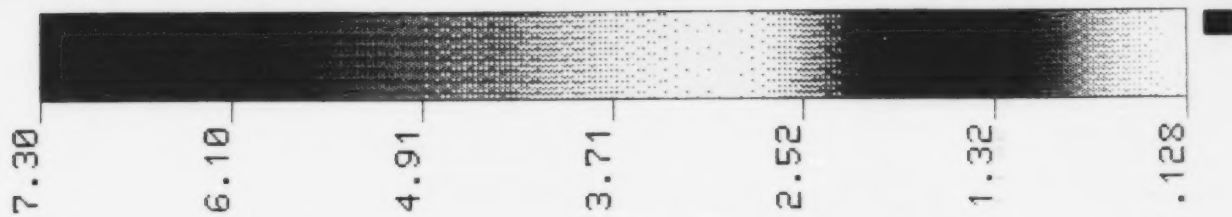


FIGURE 85

CASE 3: EFFECTIVE STRESS IN THE RIGID FOAM OF THE
IMPACT LIMITER #1 AT 0.03 SECOND (FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.03

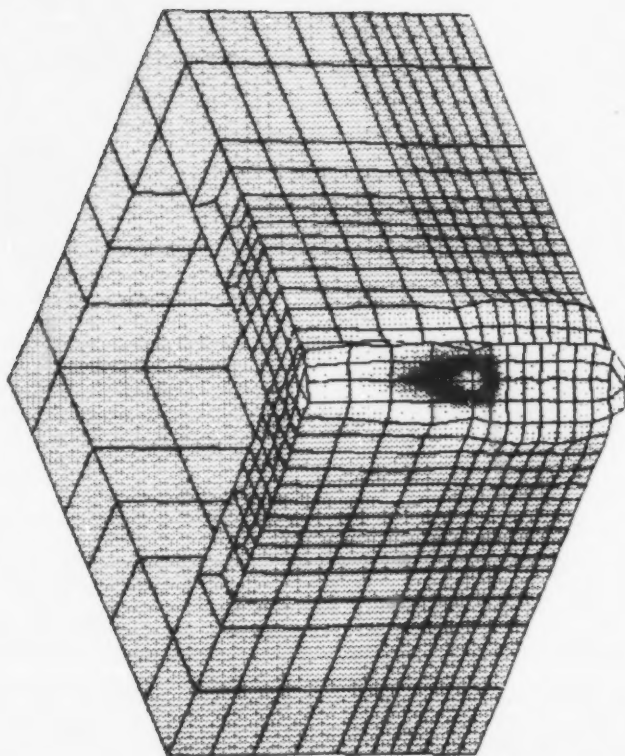


FIGURE 86
CASE 3: HYDROSTATIC PRESSURE IN THE RIGID FOAM OF THE
IMPACT LIMITER #1 AT 0.03 SECOND
(FRONT VIEW) (MPa)

CIC 9M DROP
TIME= 0.03

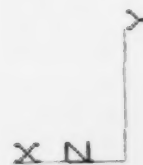
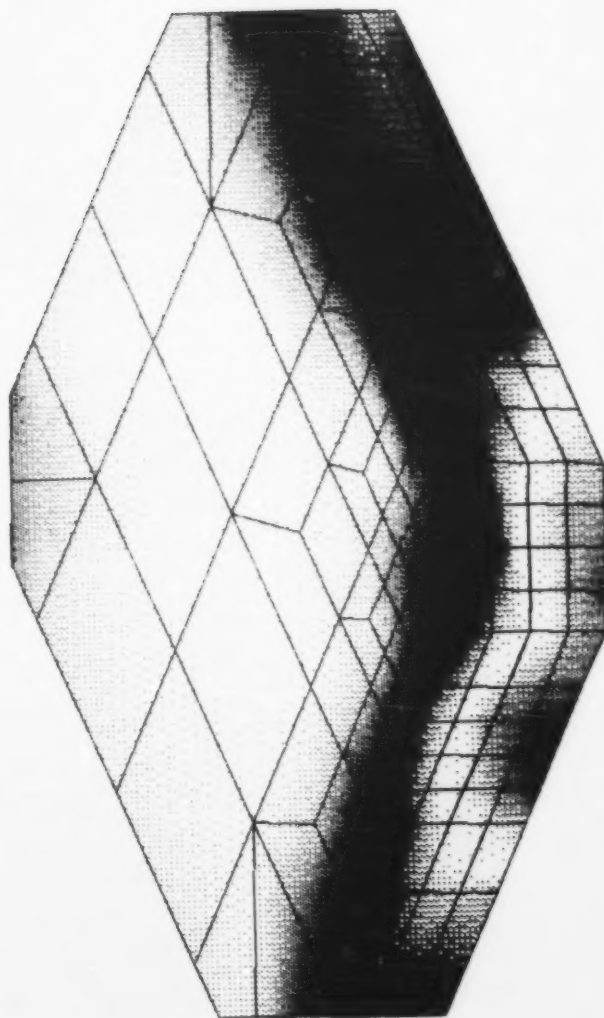
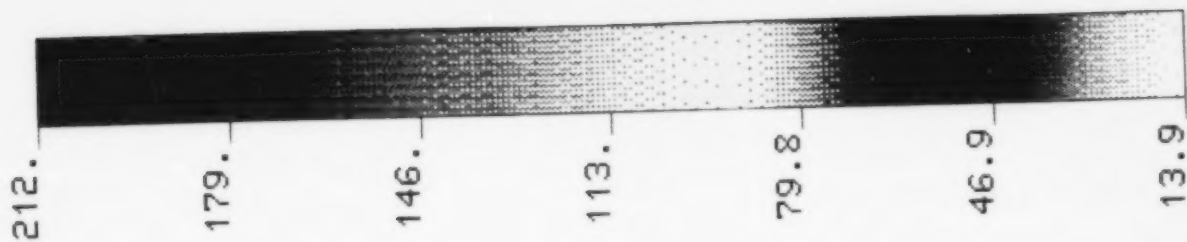


FIGURE 87
CASE 3: VON MISES STRESS IN THE LID PLATES AT
0.04 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME = 0.04

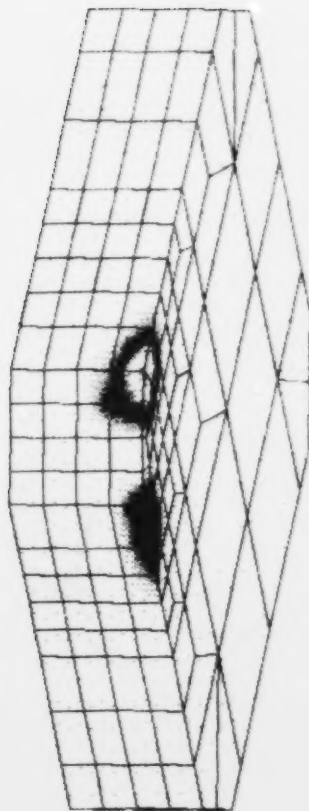
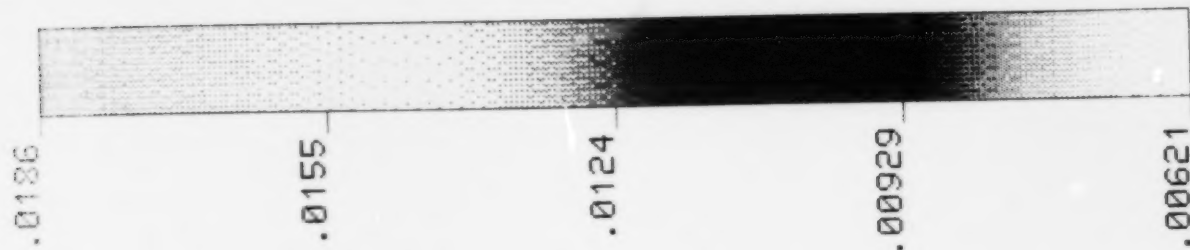


FIGURE 88
CASE 3: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE LID PLATES
AT 0.05 SECOND (BOTTOM/FRONT VIEW) (MPa)

CIC 9M DROP
TIME = 0.05

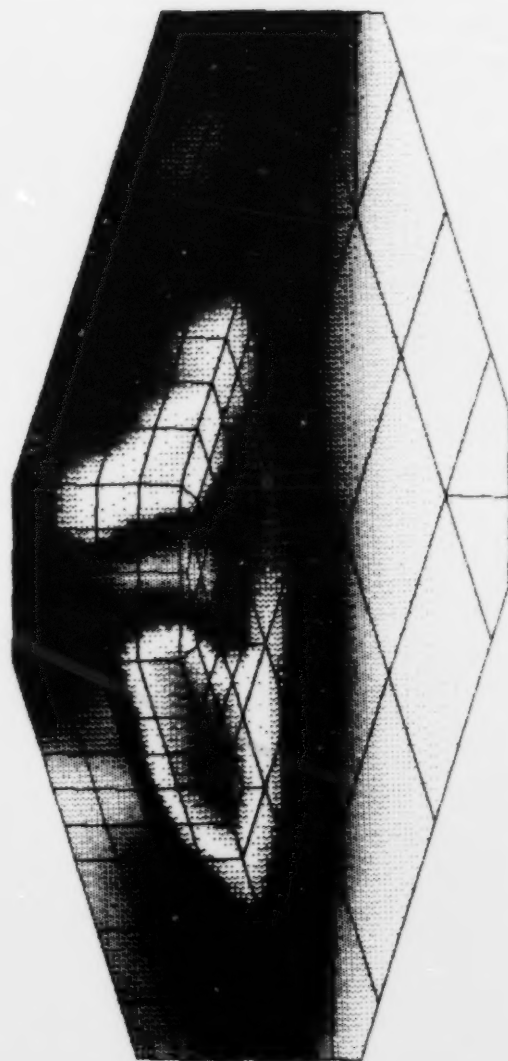
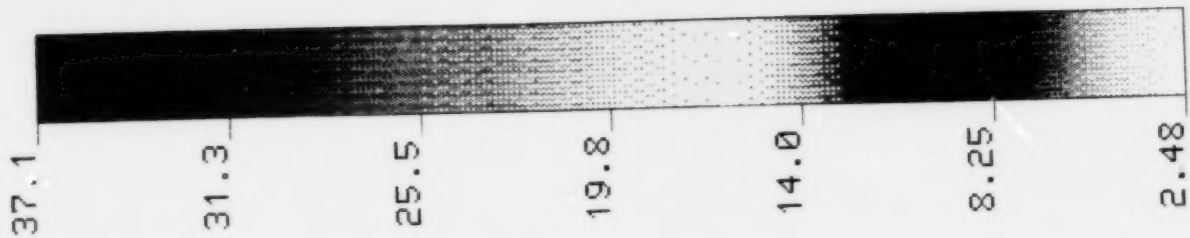


FIGURE 89

CASE 3: EFFECTIVE STRESS IN THE CONCRETE OF THE LID AT
0.04 SECOND (BOTTOM/Front VIEW) (MPa)

0.04

CIC 9M DROP
TIME =

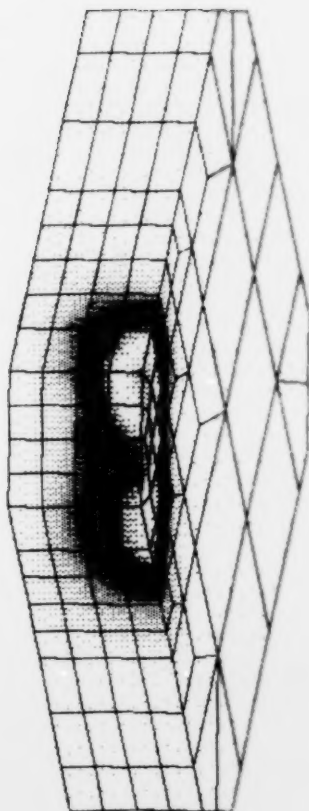
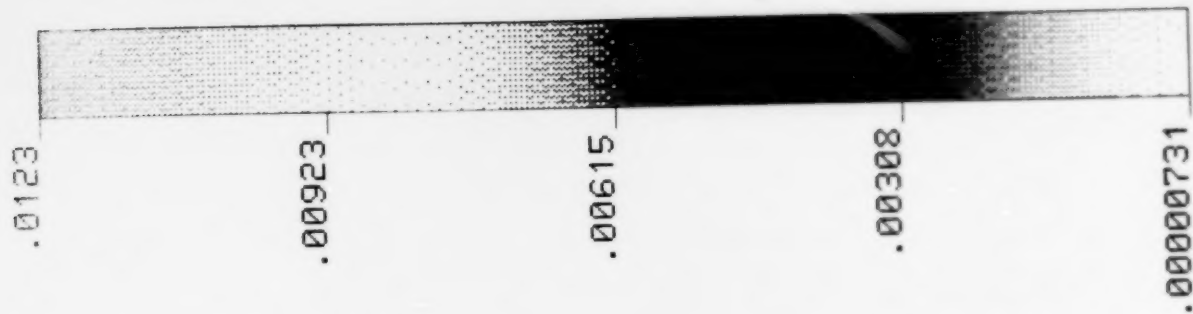


FIGURE 90

CASE 3: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
CONCRETE OF THE LID AT 0.05 SECOND (BOTTOM/FRONT VIEW) (mm/mm)

CIC 9M DROP
TIME =

0.05

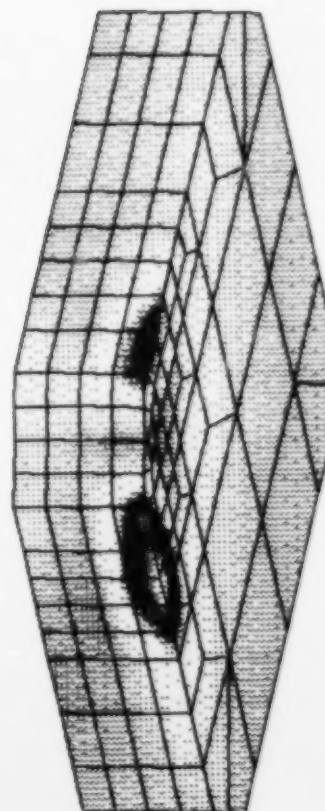


FIGURE 91
CASE 3: HYDROSTATIC PRESSURE IN THE CONCRETE OF THE LID AT
0.04 SECOND (BOTTOM/FRONT VIEW) (MPa)



CIC_9M_DROP
TIME = 0.04

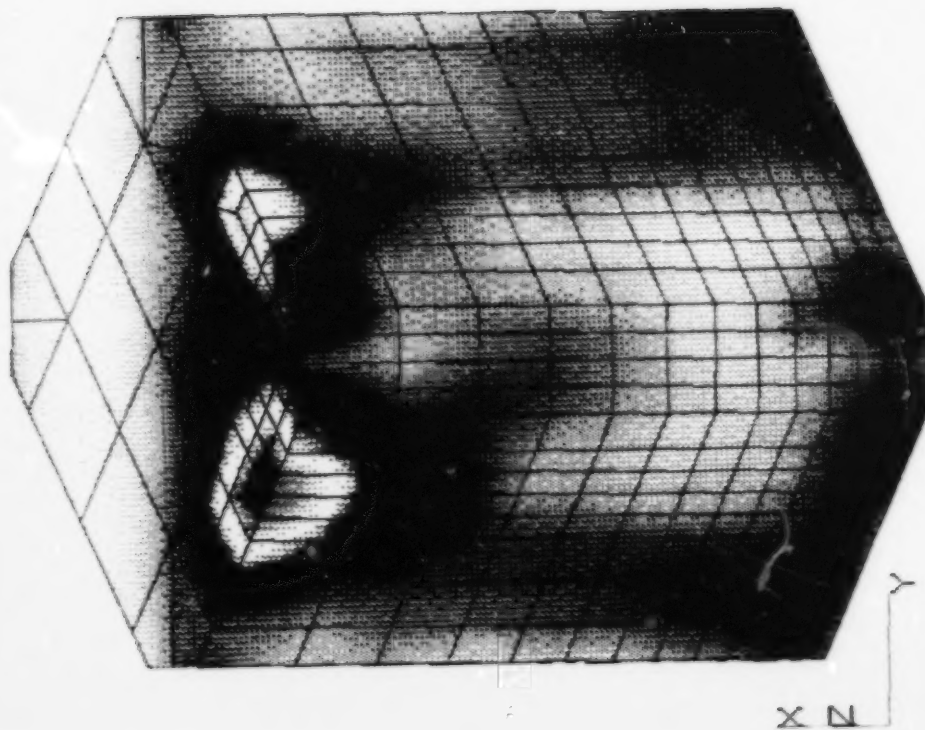
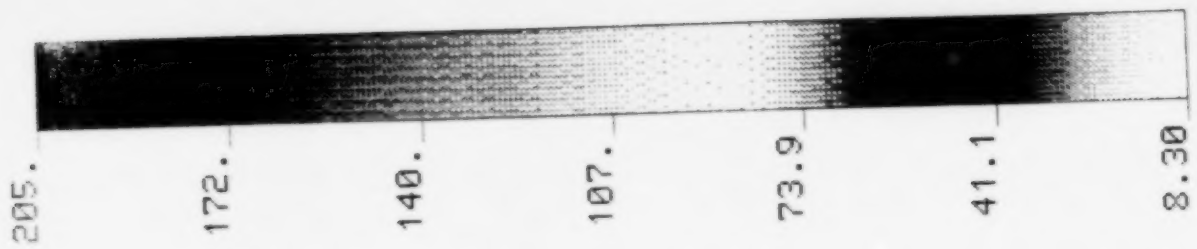


FIGURE 92

CASE 3: VON MISES STRESS IN THE CONTAINER OUTER LINER
AT 0.04 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.04

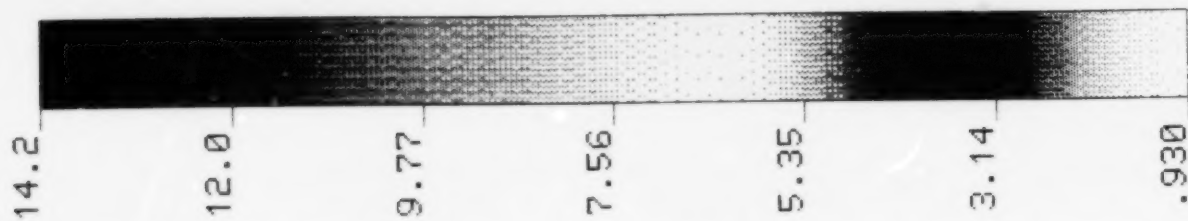
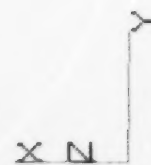
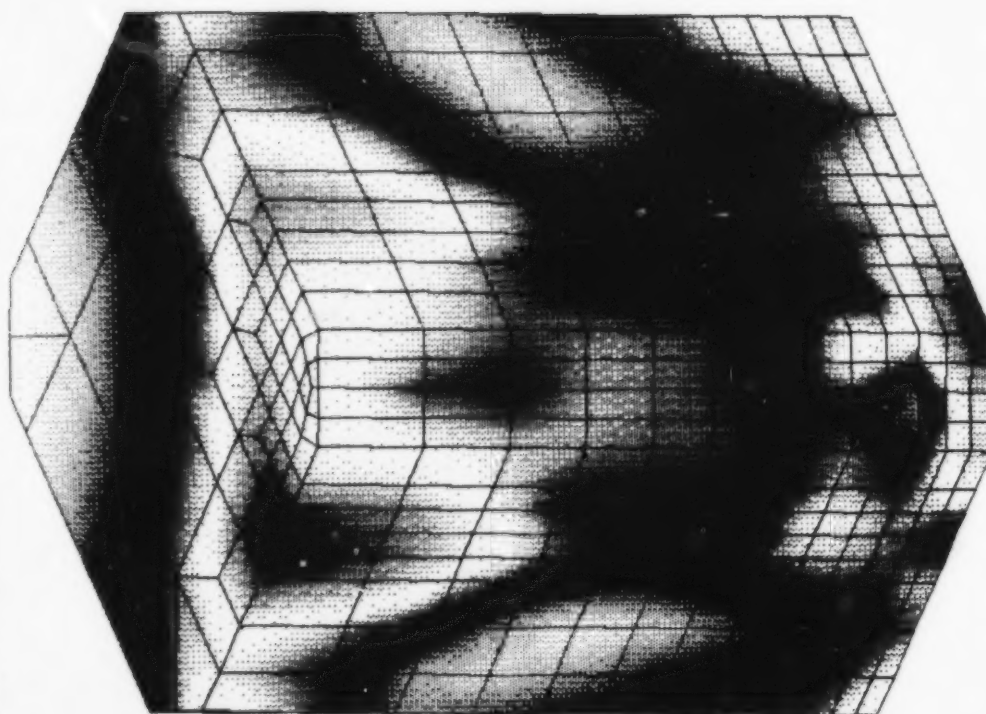


FIGURE 93

CASE 3: EFFECTIVE STRESS IN THE CONTAINER CONCRETE
AT 0.04 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.04

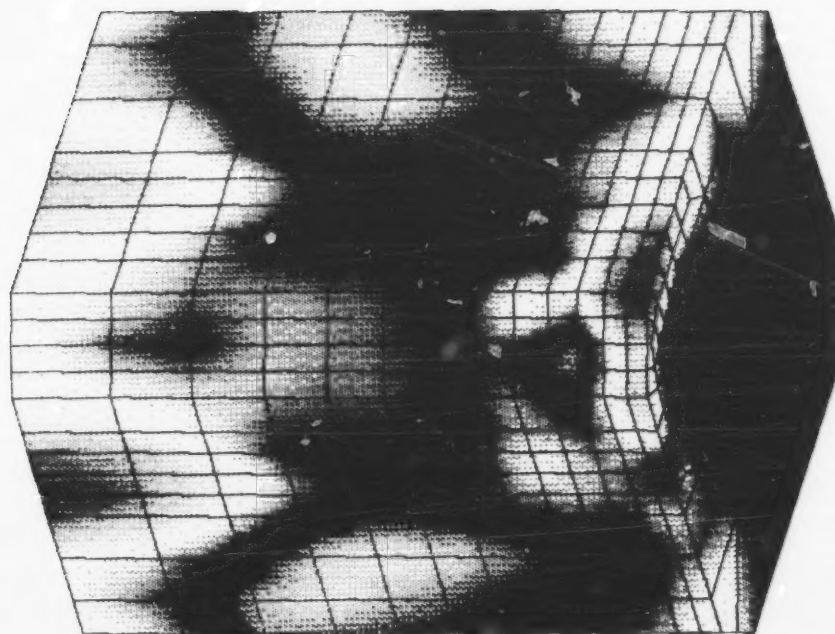
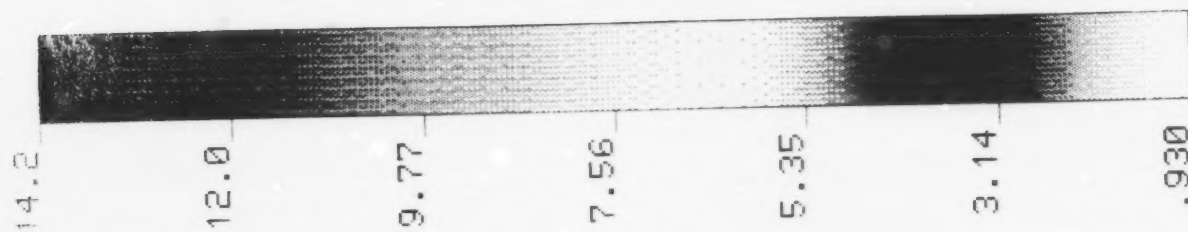
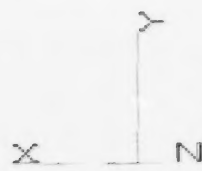


FIGURE 94

CASE 3: EFFECTIVE STRESS IN THE CONTAINER CONCRETE
AT 0.04 SECOND (BOTTOM/FRONT VIEW) (MPa)



CIC 9M DROP
TIME =

0.04

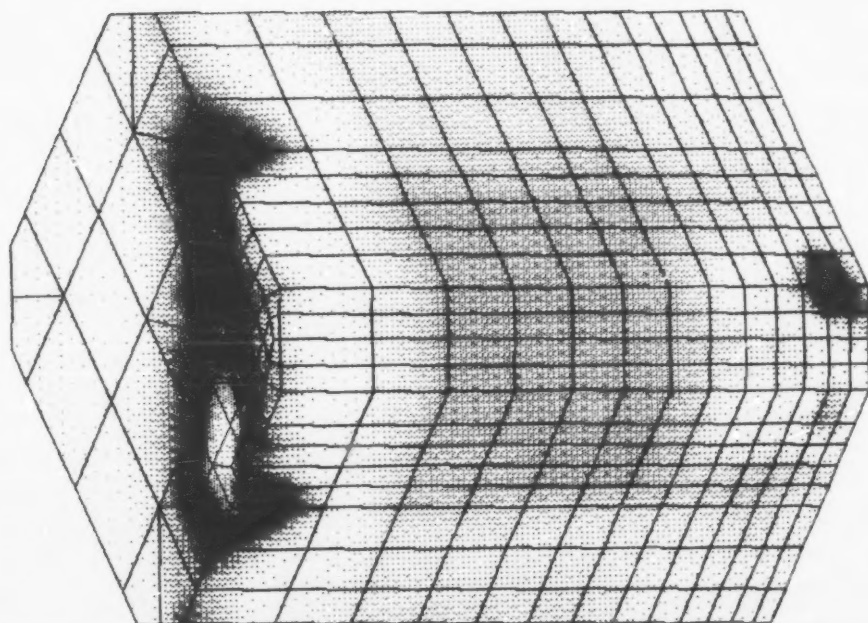
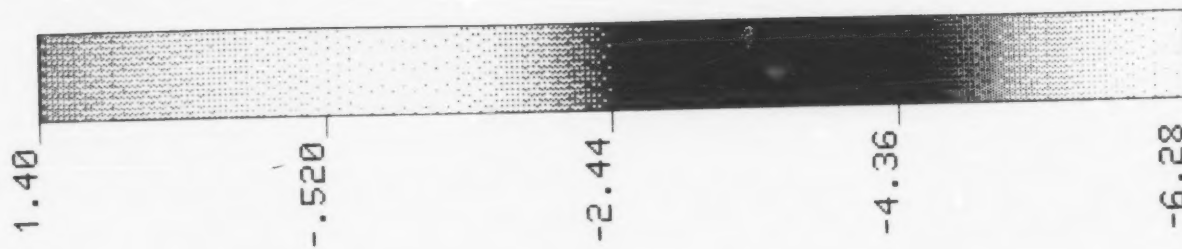


FIGURE 95

CASE 3: HYDROSTATIC PRESSURE IN THE CONTAINER CONCRETE
AT 0.04 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.04

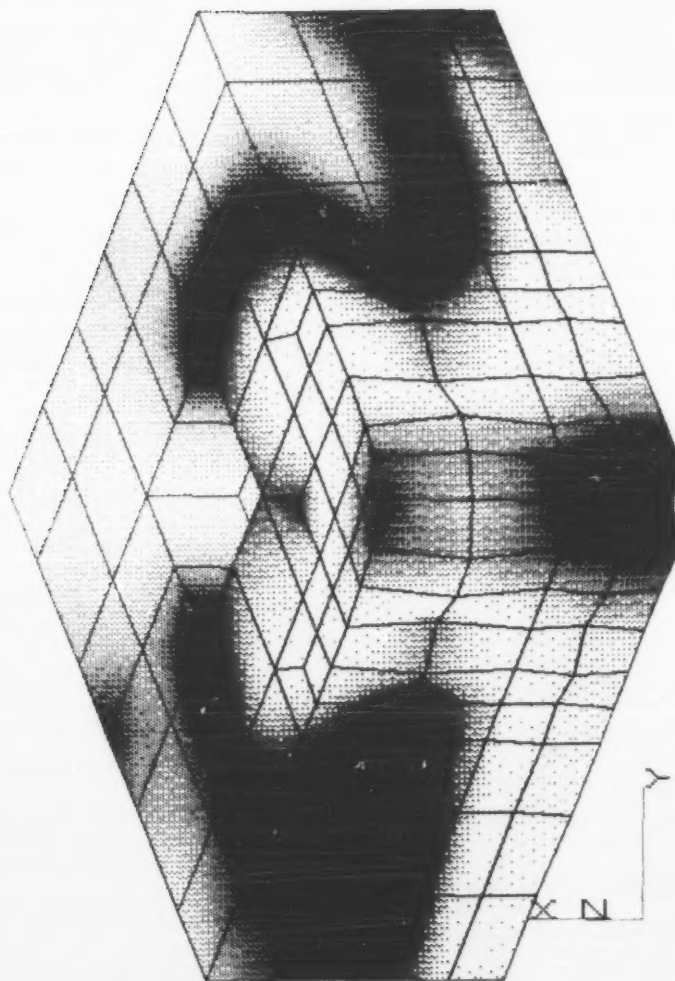
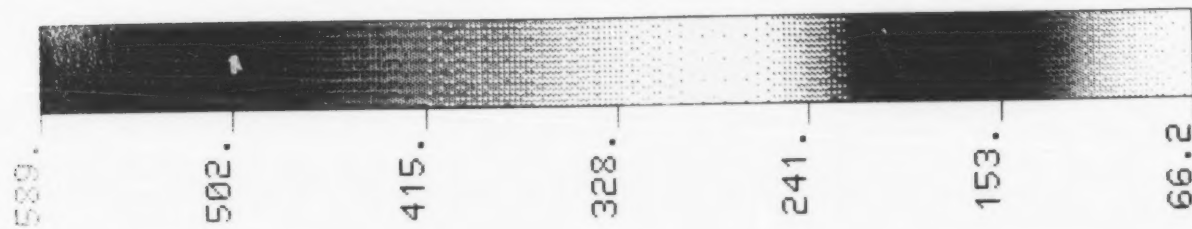


FIGURE 96

CASE 3: VON MISES STRESS IN THE STAINLESS STEEL SKIN OF THE
IMPACT LIMITER #2 AT 0.05 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME=

0.05

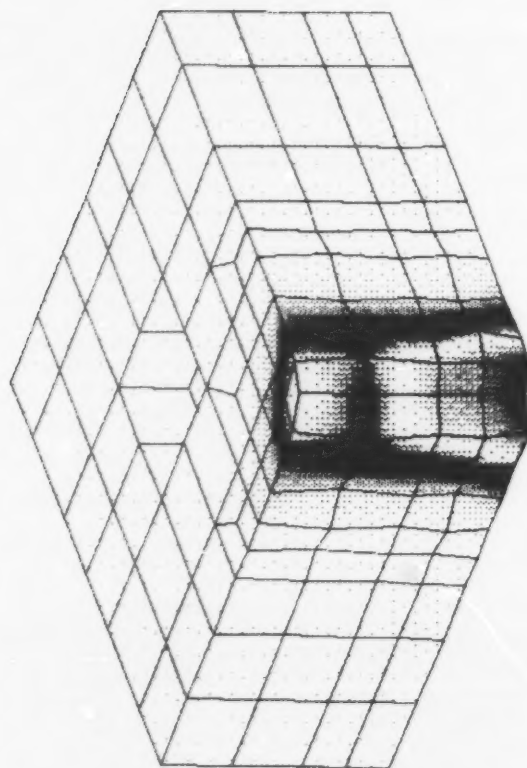
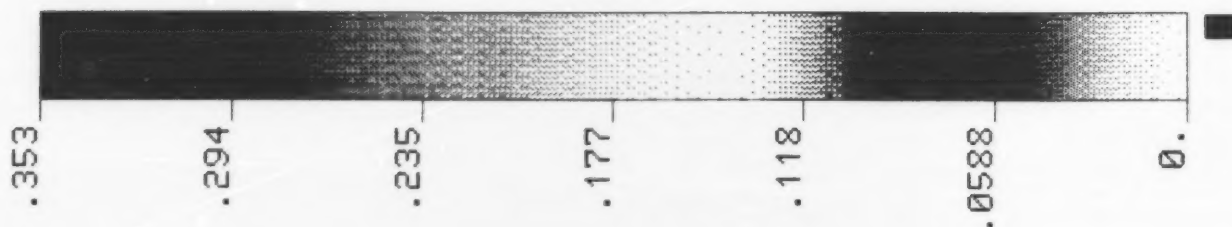
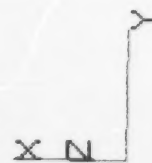


FIGURE 97

CASE 3: ACCUMULATED EQUIVALENT PLASTIC STRAIN IN THE
STAINLESS STEEL SKIN OF THE IMPACT LIMITER #2 AT
0.05 SECOND (TOP/FRONT VIEW) (mm/mm)



CIC 9M DROP
TIME =

0.05

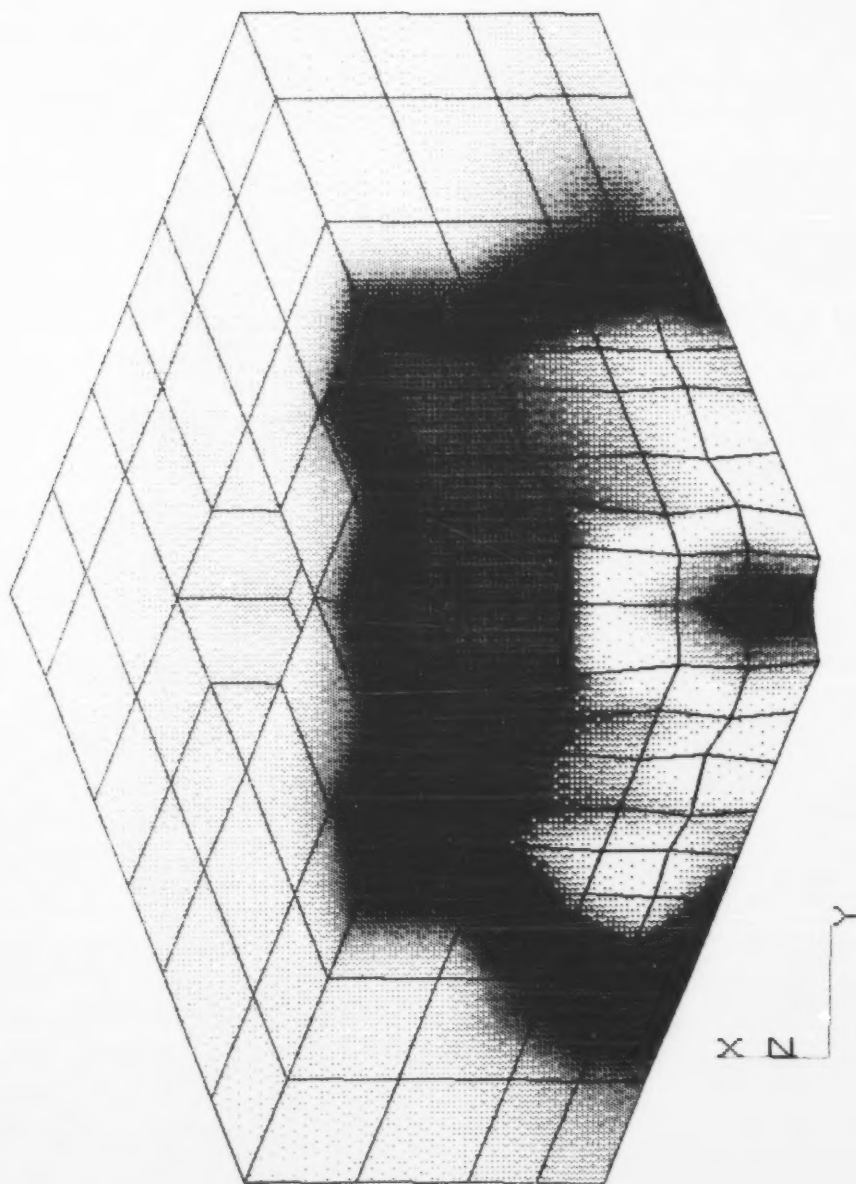
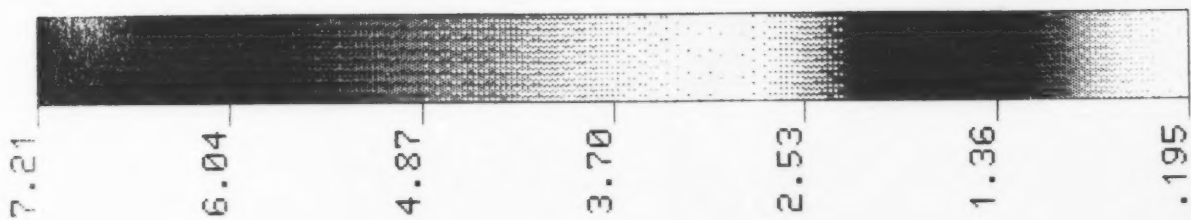


FIGURE 98

CASE 3: EFFECTIVE STRESS IN THE RIGID FOAM OF THE
IMPACT LIMITER #2 AT 0.05 SECOND (TOP/FRONT VIEW) (MPa)

CIC 9M DROP
TIME =

0.05

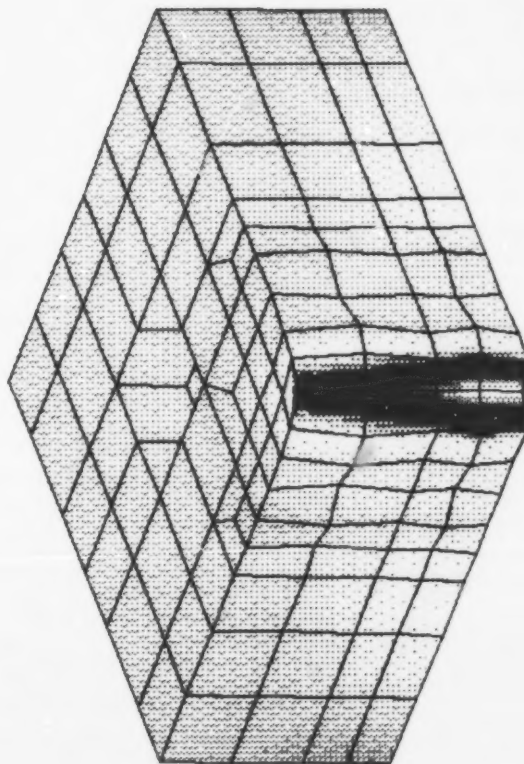
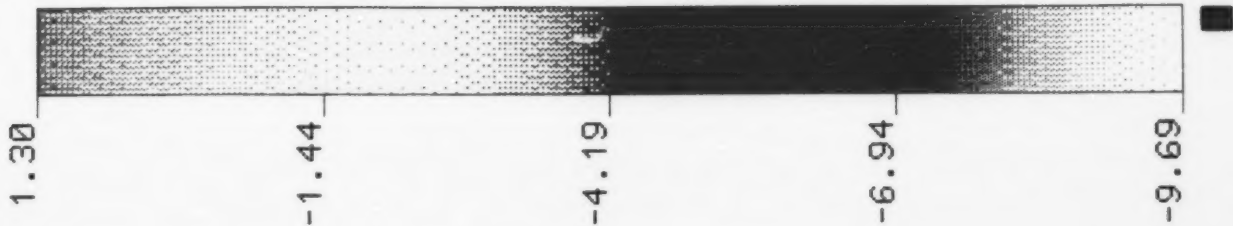
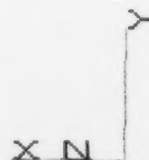


FIGURE 99

CASE 3: HYDROSTATIC PRESSURE IN THE RIGID FOAM OF THE
IMPACT LIMITER #2 AT 0.05 SECOND (TOP/FRONT VIEW) (MPa)



CIC 9M DROP
TIME = 0.05